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STUDY OF SHIP BALLASTING AND FLUID SYSTEMS FOR ICE NAVIGATION

PREPARED FOR THE
TRANSPORTATION DEVELOPMENT CENTRE
TRANSPORT CANADA

BY
INTERCAN LOGISTICAL SERVICES LTD.

IN COLLABORATION WITH
CANADA STEAMSHIP LINES INC.
MELVILLE SHIPPING LTD.

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The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transport Canada Transportation Development Centre.

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17. Abstract

This report describes various aspects of a study to identify and analyse the problems of freezing of ship ballast systems in cold climatic conditions and to propose solutions for the purpose of providing the marine industry with criteria and guidelines for designing, constructing and operating efficient ballast systems. Areas of research and development are identified.

Interviews conducted with designers, shipbuilders and operators and questionnaire replies received from many interested persons proved valuable in confirming the study members' own knowledge of the matter. This allowed the coverage of all geographical areas in which occur the freezing conditions, i.e. the Beaufort Sea, eastern Arctic, Eastern Seaboard, St. Lawrence River and Great Lakes. The government and private sectors were included.

The study deals with tank and piping systems, valves and other components or products, ice ingestion of sea water inlets and it identifies areas of research and development.

The identification and description of the problems are followed by suggestions of solutions applicable to different types of ships, climatic exposure and voyage patterns. Many problems are minor, only a few are of large magnitude. The solutions in existing vessels pertain to operating procedures and partial design changes to systems and products. New designs should consider tank and sea inlet structural changes, utilization of waste heat, supply of heat and improved products design.

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17. Résumé

Ce rapport décrit divers aspects d'une étude identifiant et analysant les problèmes du gel du lest des navires exposés à des conditions de températures froides; des solutions sont proposées afin de fournir à l'industrie maritime des lignes directrices pour le calcul, la construction et l'exploitation de systèmes efficaces des ballasts. En outre, des domaines de recherche et développement sont identifiés.

Des entrevues avec des concepteurs, constructeurs et exploitants ainsi que les réponses à un questionnaire diffusé dans les milieux intéressés s'avérèrent valables et confirmèrent les connaissances des membres de l'étude à ce sujet. Cela permit aussi d'étendre l'étude à toutes les régions géographiques où existent des conditions de gel, c'est-à-dire la mer de Beaufort, l'est de l'Arctique, la côte est, le Saint-Laurent et les Grands Lacs. Les secteurs gouvernemental et privé furent inclus. L'étude traite des systèmes des réservoirs et de la tuyauterie, vannes et autres éléments ou produits, l'accumulation de glace dans les prises d'eau de mer et détermine les domaines d'intérêt pour la recherche et le développement.

L'identification et la description des problèmes sont suivies de suggestions de solutions applicables aux différents types de navires, climat et parcours. Plusieurs problèmes sont mineurs, quelques-uns sont d'importance. Les solutions dans les navires existants ont trait aux méthodes de fonctionnement et à des changements partiels aux systèmes et produits. Les nouveaux bâtiments devraient tenir compte de changements structuraux aux réservoirs de ballast et aux prises d'eau de mer, à la récupération de l'énergie perdue et à l'amélioration de certains produits.

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1. INTRODUCTION

1.1 Foreword

Ship operators face difficult operating conditions when their ships navigate in cold climatic environments in various Canadian geographical areas, such as the lower and higher Arctic and Beaufort Sea from late spring to early fall and the Eastern Seaboard, St. Lawrence River and Great Lakes from fall until early spring. The cold ambient temperatures added to the ice or slush ice covered waters affect the ballast and the other fluid systems found aboard a ship. The severity of freezing depends on ship voyage pattern, system design and degree of coldness. The results cause a loss of ship performance, decreased security, a possible total operational stop, an increase in operating costs, and in cargo ships a loss of cargo carrying capacity.

The alternatives to solve these problems depend on ship design, ship location, crew experience, and degree of freezing conditions. Shipowners and ship operators are caught many times with the same problems season after season. They have come to develop methods to de-ice the frozen equipment and systems such as the use of steam when available, propane torches, mechanical tools, methyl hydrate, etc. All methods are time-consuming, costly and for most of them non-permanent, which means the recurrence of the problems. This had brought designers and operators to propose solutions to avoid icing of ballast and related fluid handling systems. Some of these are: circulation of ballast water through engine cooling system, anti-freeze additives, insulation materials, electric trace heating, special operational procedures, improved designs for ships committed to much prolonged Arctic operations with easy access to operating mechanisms, use of higher quality products, thermal oil heating system, etc.

Some of these solutions are more economically justifiable and operationally feasible than others. However a study to collate the information, evaluate and compare the various alternative solutions to the problems has never been conducted in the past. In the Great Lakes and St. Lawrence area this study is important since an extended navigation season is in effect now. Operations in the Great Lakes have been extended over the past recent years up to December and even into January in Lake Superior and the St. Lawrence River has been opened to navigation for some years from the Eastern Seaboard to the Port of Montréal all through the winter thus creating problems of greater magnitude than those of the past. In the Canadian Arctic, the subject becomes a necessity, given the numerous oil and gas exploration projects which have already begun, plus those to come, and the fact that ore shipments to markets from existing Arctic mines are already taking place.

1.2 Objectives

The objectives of the study are the following:

a. review and analyse ballast icing problems
b. establish criteria and guidelines for designing, constructing and operating efficient ballast system
c. identify areas of research and development.

1.3 Methodology

A data search was conducted among a good number of data banks and libraries, including those of TDC and the National Research Council. No pertinent information was found. Letters requesting information were sent to eight international societies and research centers in England, Germany, Norway, Finland and Sweden. The respondents did not have any different views than those already known here.

The study work plan that was followed included carrying out interviews with representatives of the industry. They involved designers, shipbuilders, operators, suppliers and chief engineers of vessels. The Canadian and U.S. Coast Guards were among the group. This proved the most valuable form of data gathering. It served to compare ship designs, operating profiles, equipment and systems, operating procedures, etc., to define the problems and to evaluate the solutions with the people directly involved. In addition, three questionnaires found in Appendices A, B, C were prepared, one for each group concerned with the study subject:

ship designers and shipbuilding design engineers
private ship operators.
government ship operators

106 questionnaires were sent and 34 replies received. Interviews, like the questionnaires, covered the four geographical areas of interest, namely the higher Arctic and Beaufort Sea, lower Arctic, Eastern Seaboard, St. Lawrence River and Gulf and Great Lakes. Private and government fleets were considered.

Each problem was defined, reviewed and analysed for each environment and category of vessels. Existing and new solutions were studied in relationship to their temporary or permanent nature and scope of application. Calculations were made to find their importance and to apply quantitative measures to certain alternatives. They were assessed for their practicability and cost benefits whenever the information could be available.

Ice clogging of sea water intakes was considered an important factor by the team members and this subject has been dealt with for its relationship with the use that can be made of the waste heat of the main engine cooling water and the corresponding possibility of ballast tanks to serve as heat sinks. Many operators have expressed their preoccupation with this matter.

The other subjects of domestic and sewage water and hydraulic deck lines and machinery have occasionally been mentioned as problem areas but are not considered in the report. Their extent is very limited. The solutions involve relatively minor changes to the design or operating procedures.

The M.V. "ARCTIC" is one of various vessels studied in the report; however, due to its experimental nature as an Arctic Shipping Pollution Prevention Regulations class II vessel, an addendum report is devoted to a special application in which the M.V. "ARCTIC'S" cargo holds number 2 and 4 are studied as regular ballast tanks when the ship is in a ramming mode.

2. FREEZING OF WATER IN BALLAST TANKS

Ice forms in the ballast tanks of ships in cold climate conditions particularly where ballast water is carried in side tanks above the water line and in topside tanks. The ice forms initially on the free surface of the water followed by the tank structure boundaries above the water line and exposed to the ambient air conditions.

The severity of ice build up is dependent on the operating areas of the ships and is influenced by:

a. the ambient air temperature
b. the period of time spent in cold climate
c. the length of the ballast voyage
d. the freeboard of the ship
e. the hold temperature
f. the design and geometry of the tank structure
g. wind chill factors associated with increased heat transfer coefficients and external wetted surface areas
h. the temperature of the ballast water when taken aboard
i. the salinity of the ballast and sea water
j. the temperature of sea water.

In winter months ambient temperatures fall below -40°C in many accessible areas of the Arctic maritime regions, to around -34/-37°C in the St. Lawrence River and the Upper Lakes areas, and to -29/-32°C in the Gulf of St. Lawrence and Eastern Canadian Seaboard. The freezing temperature of water varies with the quantity of total dissolved solids, varying between 0°C for fresh water and -1.83°C for "salt" water.

Each operator has experienced variations of the ballast freezing problem and has developed solutions adapted to the operating profile of their own ships.

Vessels operating in the Arctic regions of the Beaufort Sea, being predominantly drill ships, supply boats, tugs and barges are relatively small compared to the bulk carriers, freighters and tankers of the Lakes and Eastern Seaboard. The Arctic vessels operate within the limited season of June-November and are regulated by service formation. Temperatures below freezing point only occur at the beginning and end of the season falling generally to around -12°C. During this time when freezing of ballast water could occur in exposed tanks the condition of the ballast water is monitored by ship's crew and in some cases non-continuous ballast circulation is carried out at regular intervals to assure operation of the system. When any ice formation in the tanks is found, then invariably the practice is to pump out the tanks. Semi-manual removal of the ballast water remaining in the tanks after the ballast pump has lost suction is carried out by portable pumps to ensure that no water/ice can cover

the ends of the suction pipes. At the end of the season all tanks are completely drained for winter lay up. Very infrequently cases have occurred where tanks have not been emptied for the lay up period and the water has frozen with consequential distortion and rupture of the tank inner boundaries. Such cases were caused by operational error and are eliminated by stringent lay up procedures.

Vessels operating in the St. Lawrence River and Great Lakes are also regulated by the ice conditions on these waters, the season of operation extending throughout the winter in the St. Lawrence River, whereas on the Great Lakes the typical season is from April to December, but for some ships the end of the season has now begun to extend into the month of January. The problem of ice formation in the upper spaces of the side ballast tanks and in the topside tanks is very real for these operators due to the ballast tanks layout of their ships. Although the voyages are of relatively short duration, being of the order of 7 days, ice formation at the tank boundaries gradually builds up under severe cold conditions into a solid ice cover. In these conditions deballasting operations normally take place after a hole has been made mechanically in the surface ice of the tank. Ice formation also builds up along the walls of the tanks during each ballast voyage, when the vessel is delayed for several days in the light condition due to bad weather or otherwise and upon each deballasting due to the repeated wetting of the surface of the tank walls. There have been ships delayed alongside a dock for several days in the St. Lawrence and, despite partial pumping in and out of the ballast water, an accumulation of 60 cm of ice formed on all the inside walls to make up a total weight of 2,500 to 3,000 tonnes out of a total ballast capacity of 15,000 tonnes.

The problems of the upper St. Lawrence River and Great Lakes bulk ship operators were more severe than any of the other operators interviewed or surveyed by the questionnaire. The fact that the river and lakes are fresh water which freezes at a higher temperature than sea water undoubtedly contributes to the problem and all operators change fresh water ballast to salt water when reaching Québec City.

The bulk ship operators appear to live with the problem of the ice formation and the consequential loss of deadweight.

One precaution which all operators practice is never to fill the exposed ballast tanks to maximum capacity but to leave ullage at the top of the tank to allow for the change in volume from water to ice and to avoid freezing of tank vent openings.

Tanker operators have not reported problems in this respect. Most tanker vessels carry the main ballast in designated tanks within the cargo tank configuration, the tanks are never filled to the exposed deckhead and, due to their large size, the natural agitation of the water keeps it from freezing. With tankers for general trading, heating coils are fitted and may be used if conditions warrant. Changing of water level by partial discharge and filling has been practised to prevent ice formation in the case of segregated tank arrangement.

The operators in the Eastern Seaboard appear not to have any serious problems in this area. The relatively short lengths of time that the vessels spend in the cold climates undoubtedly limit the extent of the problem. With vessels trading internationally out of the Gulf, no progressive ice build up in the tanks occurs because of the repeated return to warmer climates.

Special service ships have been grouped to include navigational aid vessels, survey ships, ferries and tugs. They mostly carry ballast in double bottom tanks and side tanks below water line and have not been reported to have problems.

Non commercial vessels, such as government icebreakers, carry some permanent ballast but have a limited operating season dependent on the ice conditions. Problems of frozen ballast water in exposed tanks have been experienced, but are now dealt with by either discharging the ballast or leaving ullage at the top of the tanks and living with the problem. Other problems associated with ballast tanks were found to exist, such as freezing of water in air pipes at the top of the tanks, water left in empty tanks around the ballast suction bellmouth, and in and around sounding pipes.

Cases did occur where ballast tanks were unintentionally pressed up to maximum capacity and water in the exposed air pipes froze in the cold climates. Isolated cases have occured of damage to the tank structure on commencement of deballasting due to tank vacuum. Antifreeze liquid and mechanical clearing have been the remedial actions taken.

The solutions to the problem of ballast water freezing lie in the hands of owners, ship designers and operators.

Due to the present existing operating profiles of Canadian vessels the problem is small in magnitude. St. Lawrence River and Great Lakes operators are being affected to the largest extent. They have developed operating procedures and minor design changes which appear to cope adequately with the problem. The effects of ballast water freezing in the form of ship downtime, loss of deadweight and cost of marginal additional equipment or of small changes in design from conventional practice have not been severe enough to warrant major design changes nor capital expenditures

However, as the operating period in the Lakes extends and expansion of activity in the Arctic regions progresses to year round operation the problem will undoubtedly become much more acute if remedial measures are not taken.

The solutions available fall into four categories.

1. Structural design
2. Application of heat
3. Operating procedures
4. Provision of equipment.

2.1 Structural Design

In the initial design of the vessel particular attention should be focused on the necessity of having exposed tanks above the water line for ballast purposes. If possible ballast should be carried below the water line to eliminate ballast water heat loss to ambient air. It is considered that the application of this aim will become in the future one of the major design parameters for vessels with prolonged cold climate operation. The carriage of water ballast in double bottom tanks and side tanks below the water line must of necessity involve some departure from present structural arrangements and lead to special configurations and characteristics for dedicated winter operating vessels. The centre of gravity of the ship in the ballast condition will be lowered resulting in a large GM and stiffer ship than would otherwise be the case. The trim of the ship and the required draught in the ballast condition will need careful assessment so that propeller immersion and sea keeping qualities are not sacrificed particularly with the advent of high efficiency large diameter propellers. If the change in ballast distribution resulted in a decrease in deadweight this would be very unpopular with commercial operators but the breadth of the hold may be extended to the ships side above the water, providing stability in the loaded condition is satisfied. Another possibility exists in the carriage of fuel bunkers in side tanks above the water line. This solution has only specialized application dependent on the operating profile of the ship and the type of fuel burnt. It may be practical for dewaxed diesel oil but would not be suitable for the heavier bunker grades. It should also be noted that this area of the vessel is most susceptible to puncture thus causing an oil pollution problem.

If ballast must be carried above the water line the provision of heating for those ballast spaces will be required for prolonged cold climate exposure. In this case it would be beneficial to separate the wing ballast spaces above the water line from those below so that the quantity of ballast water to be heated is considerably reduced.

A void space outboard of the ballast tanks could separate the water ballast from the outside ambient air conditions and the layer of stagnant air would reduce the heat loses due to the lower film heat transfer rates. However, the loss of deadweight, the requirements for access inside the skin and additional steel and construction costs preclude this design, particularly for commercial operators.

2.2 Ballast Heating

Ice formation will be prevented if the temperature of the ballast water is maintained above the freezing point. More specifically, the heat input to the water should be equal to or greater than the heat loss to the ambient air conditions. The heat loss takes place not only through the outer shell and deck plating but also through the inner tank bulkheads to the cargo holds. The loss is dependent on the ambient temperature conditions, the area of the exposed surfaces and the heat transfer coefficient in accordance with the standard formula:

heat loss = overall heat transfer coefficient x heat flow area
x temperature differential

Additional considerations arise with fresh water ballast, as a heat loss will also occur to salt sea water, at a freezing point some 1.83°C below fresh water.

The determination of the overall heat transfer coefficient involves the summation of the coefficients of all the layers along the heat path. Although the coefficient for the steel material is well known, little precise information is available for the film coefficients at the hull steel/sea water, hull steel/ambient air, hull steel/ballast water interfaces for different ships and air velocities. The film heat transfer coefficients may be determined analytically from the following formula:

$$\text{film coefficient} = \frac{c}{x} \cdot Nu.$$

Where c = thermal conductivity of fluid
x = characteristic length
Nu = Nusselt No.

For free convection $Nu = K_1 (Gr \times Pr)^{K_2}$

for forced convection $Nu = K_3 (Pr^{K_4} \times Re^{K_5})$

where Gr = Grashof No.
Pr = Prandtl No.
Re = Reynolds No. and
K_1, K_2, K_3, K_4, K_5 = constants.

In the final analysis, however, the analytical results must be correlated with experimental results. In these circumstances, the required heat input to the ballast tank may only be estimated and a suitable scale factor applied to take account of the accuracy of estimation. Of the three factors in the heat loss equation, the only parameter that can be controlled by the designer and owner is the exposed area of the tanks, and this has been addressed above under Structural Design.

The application of heat to the ballast tanks involves two aspects:

a. source of heat
b. means of transfer to and within tanks.

The heat source may be waste heat from the engine room machinery or separately generated by the combustion of additional fuel in suitable equipment such as boiler, calorifier or thermal oil heater.

The means of distribution to the tanks could be through heating pipes within the tanks, or by direct circulation of water through dedicated heaters in the machinery space with the tanks connected in a series or piped in a parallel configuration. The uniform distribution of the heating fluid to all the tanks would undoubtedly require

careful design and control.

The distribution of the heat throughout each tank, particularly in the upper spaces exposed to ambient air conditions, will present problems due to the internal structure of the tank, obstructing circulation to the boundaries on which ice is prone to form.

2.2.1 Source of Heat

Table 1 lists the heating equipment or machinery available to provide the sources of heat, the primary heating fluids involved, the quantities of heat energy available from the primary fluid, and the fluid options for secondary and tertiary heat exchange mediums.

In the case of vessels already equipped with some measure of waste heat recuperation, additional fuel requirements would be required.

It has been assumed that the machinery arrangements incorporate oil engine prime movers, as is typically the case in the Canadian marine field.

The application of salt water heaters in the uptakes of main and auxiliary engines has not been considered nor direct contact water heaters burning liquid fuels due to the corrosive effects of hot salt water and the acidic components in exhaust gases.

The heat available from the primary fluid is naturally dependent on the operation of that heat source, which in the case of the main engine of the vessel is not always in use. The available heat values in Table 1 do not include the heat rejected in the charge air coolers of the engine as this will be much reduced at the low ambient temperatures under consideration, and this provides some measure of conservatism in the heat available estimates. The heat exchange system would normally involve only the primary and secondary heating fluids, and for secondary fluids prone to freezing themselves, an efficient drainage arrangement of that system would be required. This problem could be overcome at some cost by using an additional heat exchange process introducing a tertiary heating medium not prone to freezing.

	Heat Source	Heat Available from Source	Primary Heating Medium	Secondary/ Tertiary Heating Mediums
A	Main engine	12% of main engine fuel energy	exhaust gas	steam/fresh water/glycol/ thermal oil
B	Main engine	14% of main engine fuel energy	engine cooling water	fresh water/ glycol/thermal oil
C	Separately fired steam boiler	87% of fuel energy	combustion gas	steam/fresh water/glycol
D	Separately fired hot water boiler	89% of fuel energy	combustion gas	fresh water/ glycol
E	Thermal oil boiler	89% of fuel energy	combustion gas	thermal oil

Table 1 Ballast Heat Source Options

Heat sources A to D in Table 1 involve recuperation of waste heat which may otherwise be lost to atmosphere. The use of such heat is economically very attractive. In order to assess the magnitude of the ballast heating requirements of some typical Canadian vessels, the heat loss to atmosphere has been estimated for different ambient air temperatures for three bulk carriers, the M.V. "ARCTIC", and two typical laker vessels denoted GL1 and GL2. Their characteristics are given in Table 2A. This assessment must be made before appraising the methods to prevent freezing of the water. The parameters used in the assessment are given in Table 2B. All three vessels are double-skin bulk carriers with ballast water carried in side and bottom tanks surrounding the hold spaces.

Vessel	"Arctic"	Great Lakes Vessel 1 (GL1)	Great Lakes Vessel 2 (GL2)
Date of Build	1978	1972	1966
Length of Ballast Spaces	148 m	188.3 m	177.2 m
Ship Breadth	23.1 m	23.1 m	22.8 m
Ship Depth	15.4 m	14.3 m	12.3 m
Ballast Draught	11.1 m	4.9 m	5.2 m
Main Engine	----------Oil Engines----------		
Horsepower MCR	14,770	8,200	9,600

Table 2A Typical Canadian Bulk Carriers

Overall heat transfer coefficients by
$1.05 \times 10^3 J / 9.3 \times 10^{-2} m^2$ hr .55°C (BTU/ft^2 hr °F)
(Vessel steaming 15 Knots)

Ballast water to - ambient air, vertical path	6.2
- ambient air, horizontal path	5.4
- still air in hold, vertical path	1.5
- still air in hold, horizontal path	1.3
- sea water, vertical path	55
- sea water, horizontal path	60

Table 2B Heat Loss Coefficients

The results of these assessments are shown in Figures 1, 2 and 3, respectively for the three vessels, and show the magnitude of the heat loss in the temperature range -40°C to 4.4°C for different ballast water keeping temperatures. The temperature of the air in the cargo hold has been assumed to be between the ballast water temperature and the ambient outside air temperature in proportion to the tank and hatch cover contributions to the hold perimeter length. A sea water temperature of -1.66°C has been assumed. Also shown in the Figures are the recoverable quantities of main engine waste heat on the basis of percentage of engine maximum continuous rating (MCR) and on an overall heat transfer efficiency from source to ballast water of 80%.

With reference to Figures 1, 2 and 3, when the ballast water temperature is equal to the sea water temperature, the heat loss is solely to the ambient air around the vessel and into the empty cargo hold. This quantity is shown below the "-1.66°C ballast water temperature" line. In an ambient temperature of -40°C this loss has

been estimated at

12.4×10^9 J/hr for the M.V. "ARCTIC"
19.9×10^9 J/hr for the Great Lakes vessel 1 (denoted GL1)
8.2×10^9 J/hr for the Great Lakes vessel 2 (denoted GL2).

The difference in heat loss between the vessels is due to the variation in exposed surface areas to the ambient air, viz the freeboard. To provide this heat from a primary fuel source heater with an 89% heat transfer efficiency the fuel cost/day would be:

$C 2,784 M.V. "ARCTIC"
$C 4,460 GL1
$C 1,840 GL2

based on marine diesel oil at $C 360/tonne. This price serves as a comparative base only. The actual cost varies with the type of fuel used.

If the recoverable heat from the main engine cooling water only was used to assist in the prevention of ballast freezing, then at 70% MCR engine load, freezing would still occur below -9.4°C for GL1. To prevent freezing below these temperatures then additional heat from a primary fuel source heater would be required and the marine diesel oil fuel cost for every further .55°C drop in ambient temperature would be:

$C 40/day M.V. "ARCTIC"
$C 65/day GL1
$C 27/day GL2

Under these conditions, the cost of the additional fuel/day in ambient temperatures of -40°C would be:

$C 1,160 M.V. "ARCTIC"
$C 1,885 GL1
$C 1,485 GL2

These costs may be compared with those above to gauge the benefit of utilizing main engine waste heat. However, their magnitude in either event is considerable.

If the recoverable heat from both the main engine exhaust and the cooling water is utilized, then with similar assumptions, the ballast water could be prevented from freezing down to -40°C ambient for the M.V. "ARCTIC" and GL2 vessels, but to only -15.6°C in the case of the GL1 vessel. However, there may well be other systems on board a vessel requiring the use of engine exhaust waste heat such as steam generation for machinery and ships heating, fuel heating or electrical power generation. The use of only one of these two heat sources therefore provides a realistic assessment of additional primary fuel requirements.

Any proposal to raise the ballast water temperature above the sea water temperature also involves heavy cost penalties due to the heat loss to the sea water. For an increase in ballast water temperature of .55°C above the sea temperature the heat losses to the sea for

the three vessels considered would be in the range 3.8 to 4.2 x 10^9 J/hr, and the cost of providng this heat from a primary marine diesel oil fuel source would be $C 850 - 950/day.

For a prolonged exposure period an assessment of the costs of providing additional fuel to satisfy the ballast heating requirements may be made with the following assumptions:

Sea water temperature	- 1.66°C
Ballast water temperature	0 °C
Ambient air condition	-17.80°C
Exposure period	60 days
Main engine load	70% MCR with utilization of main engine cooling water waste heat (Ref. Figures 1, 2 and 3, B) for ballast heating.
Thermal efficiency of equipment using additional fuel	89%
Marine diesel oil	$C 360/tonne [1]

From Figures 1, 2 and 3 the quantity of heat required would be:

M.V. "ARCTIC"	16.1 x 10^{12} J
GL1	24.1 x 10^{12} J
GL2	14.6 x 10^{12} J

and the operating fuel cost for the period would be:

M.V. "ARCTIC"	$0.15 million Can.
GL1	$0.23 million Can.
GL2	$0.14 million Can.

The use of main engine cooling water heat amounting to some 14% of the fuel energy of the main engine has been used as an example to show the effects of utilizing waste heat. Similar treatment for the main engine exhaust gas may be made and would yield slightly smaller quantities due to the recoverable heat quantity, viz 12% of main fuel energy, and a lower heat transfer efficiency of such a system.

In comparison with the heat requirements of the ballast water, the available waste heat from other waste heat sources on board is very small and may be utilized for other duties such as assistance in preventing ice build up in sea inlets. Figure 4 shows three alternative arrangements for heating the ballast water using main engine waste heat in conjunction with separately fired boilers.

In summary the solution of supplying heat to the ballast water to prevent freezing involves heavy operating cost penalties in fuel alone, and to these must be added the capital costs of design changes, additional equipment and maintenance costs.

1 Actual cost varies with type of fuel used.

The application of this solution depends heavily on the operating profile of the vessel for economic viability, and each application would need careful assessment.

2.2.2 Means of Heat Transfer

The available options of transferring heat are to either pump the ballast water to the heating equipment, or to circulate the heating fluids in the ballast spaces.

The first option will require dual piping circuits through and to each of the ballast spaces to be heated, each circuit being similar to the ring main system presently fitted in some vessels. A schematic layout diagram for such a system is shown in Figure 5; the ballast water continuously circulates from all tanks with suction and discharge pipe ends sited at opposite ends of each tank. Provision is made to reverse the circulation direction if necessary, to incorporate a heater in the circuit, and to utilize the ballast pumps of the ship.The complete side and double bottom tank capacities would be circulated in approximately 12 hours using typical ballast pump capacities.

The difficulty remains however in distributing the heated ballast water to the areas of the tank space most likely to freeze, and also to ensure even distribution of the piped water to each of the tanks. For current designs with integral side and double bottom tanks the distribution of the heated ballast to the upper spaces of the side tanks is necessary and would require extended vertical pipe lengths in each tank for suction and discharge. This would ensure a positive heated circulation across the top of the tanks, but an additional valved branch off the ballast main for each tank would be required for normal deballasting operations. Position control of the circulation valves would be required to maintain even heat distribution and to maintain tank level and this aspect is seen to present the greatest technical problem which may not be successfully overcome except by trial and error.

An alternative may be considered by circulating the ballast tanks in series, say from forward to aft, on an overflow principle. This would greatly reduce the control problem of tank level maintenance and ensure circulation across the top of the tanks. However a longitudinal temperature gradient would exist through the tanks and additional heat need to be supplied to prevent freezing in the tanks at the end of the flow path.

The second option of transferring heat to the ballast water involves the use of heating pipes in the tanks. In all vessels carrying heavy oil for cargo or fuel duties this is the universal method of tank heating. Figure 4B shows schematically the general system for motor ships.

A simple method of transferring heat to the ballast water would be by circulating the main engine sea water cooling waste heat through the ballast ring main. However, for maximum effect the system would

preferably be a separate pipe loop or series of loops through the upper spaces of the side tanks at the water line level. To assess the capability of the system, and on the assumption that the ballast water is regarded as an infinite heat sink, it is estimated for the M.V. "ARCTIC" that a temperature differential of 10.6° C between the pipe fluid at inlet to the ballast spaces and the ballast water would be required in order to dissipate the engine cooling water heat at 85% MCR engine load through the walls of the single pipe ballast ring main. However, reference must be made to Figure 1 for an indication of the probability of freezing taking place. The arrangement illustrates a simple and relatively effective way of overcoming freezing problems without the complication of an extensive heating pipe system when air temperatures are not too severe. The system may be further adapted to utilize the main engine exhaust waste heat as shown in Figure 4C using an uptake heating coil.

The provision of dedicated heating pipes in tanks is the conventional method of tank heating but, in this context, the temperature ranges under consideration are significantly lower and the heat should preferably be applied in the spaces of the upper side tanks exposed to the ambient air if heating costs are to be kept to a minimum.

The type of layout of the heating pipes in the tanks themselves depends on the geometry of the tank. On the premise that the heat should be applied to the upper spaces of the side tanks in way of the water line, then a horizontal layout would distribute the heat most effectively. However, as experience indicates that ice formation begins at the tank boundaries, the heating pipes should be run as close as possible to the tank walls. Longitudinal stiffening in the tanks would inhibit natural circulation, and scalloping of the stiffeners would be required.

A grillage layout, similar to conventional practice, involving relatively small diameter piping would require extensive pipe lengths and pipe supports, introduce considerable pressure drops in the circuit, introduce unwanted drainage problems and would not be recommended.

An alternative arrangement using fresh water/ethylene glycol as intermediate system fluid would be to have a fresh water/ethylene glycol coil bank in the main engine uptakes as a hot water generator. This may be linked to the main engine cooling system and an additional separately fired hot water boiler added to the circuit to provide the necessary heating requirements in the very cold climates. Figure 4A shows a basic arrangement. Such a system provides a considerable margin for heat generation to suit different climatic and operating conditions and at a considerably reduced operating cost compared with a total primary fuel heat source. The use of the heat transfer medium to the ballast spaces may require an additional heat exchanger and pumping system in the machinery space.

Another alternative which appears to have found some favour with a few cold climate operators utilizes a thermal oil heating system.

This is a variation of the hot water boiler with the difference that the fresh water/ethylene glycol is replaced by thermal oil. Development of shipboard thermal fluid heating has grown over the past 10 years and plant capacities have gone from small sizes of a few hundred kw to large ones of over 10,000 kw. Page 30 provides more information on the subject.

The piping of the heating fluid to the ballast tanks will require to be suitably insulated and the options of running the pipes through the tanks, through the hold space, along the deck or in a pipe tunnel are available. Of these, the provision of an enclosed pipe tunnel or duct keel would be the most practical from an operational point of view.

The cost to supply and install heating coils in ballast tanks and to modify hardware to ensure prevention of freezing on a standard size lake vessel could run as high as $1,000,000. or more. It is to be noted that designs and construction costs are required to properly estimate the cost of a particular option, a task beyond the scope of this study.

2.3 Operating Procedures

The operating procedures to prevent ice formation and build up in ballast spaces are dependent on the area of operations of the vessels. At the present time the following methods are used for particular situations:

a. partial pump out and refill intermittently
b. continuous circulation of ballast water
c. reduction of ballast tank water level to vessel water line
d. change of fresh water ballast for salt water ballast
e. complete drainage of ballast tanks
f. ice removal by mechanical means.

Although some of these methods are suitable for relatively short voyages in cold climates they are obviously unsuitable for prolonged exposures and more permanent methods will be required to be provided. Only e above is suitable for prolonged exposures and a, b, c and d have limited application.

Circulation of unheated water, which a and b effect in a discontinuous and continuous basis and appears to give some measure of protection from ballast freezing, provides replacement of the boundaries layers in the ballast spaces either with water at a marginally higher temperature, or with water which has not lost any latent heat of fusion. The temperature difference may be due to the heat input from the circulating pump, and the spaces through which the piping is situated, or by virtue of a temperature variation within the ballast tank. It is known that water has a maximum density approximately 3.8°C above its freezing point and that a temperature gradient exists with water depth. See Figures 6 and 7 taken from Reference 1 and Figure 8 taken from Reference 4 which show the variation of temperature and salinity with water depth for the

Beaufort Sea for the end of winter and summer periods respectively. However, the variation seldom exceeds 0.14°C in these areas for depths up to 60 metres. (Ref. 4). The temperature variation in the Great Lakes, the Gulf of St. Lawrence, and the Eastern Seaboard and Arctic regions is not known, but is dependent on many factors including currents and seabed depths. If a temperature gradient exists within the ballast draught of the ship then heat transfer will take place from the sea water to the ballast water through the ships sides and, in the absence of known natural circulation conditions, forced circulation would be needed to transfer the heat to the upper spaces. The quantity of heat transferred is difficult to quantify due to a lack of knowledge of the variation of sea water temperature with depth for the various shipping regions, particularly in the range of ships draught. Any proposed method of preventing ballast water freezing in vessels with combined side/DB tanks should incorporate the provision for forced circulation of the system to take advantage of this possible low grade heat source.

2.4 Provision of Equipment

Other solutions independent of tank design or engine and boiler heat sources have been explored. They relate to methods of water circulation and tank insulation.

2.4.1 Air Bubbler System

Another method of ensuring circulation of water within the ballast spaces is an air bubbler system. The equipment of compressors, piping and valves have previously been fitted on vessels but for different reasons. The system has found application in shallow waters for keeping tracks of water free of ice for ferry operations and for laid up vessels in the Great Lakes during winter. The principle of the system involves the circulation of warmer sub surface waters by the surface tension of the air bubbles rising to the colder surface areas. The application to shipboard ballast tank circulation in the context of this study is very questionable. The system would rely on the temperature of the water at the bottom of the ballast tanks being higher than the temperature at the top, and for any appreciable effect to be made on the prevention of surface freezing over the range of ambient temperatures envisaged would require that such a gradient exists.

It is estimated, for ambient temperature conditions of -40°C and a 0.55°C temperature differential between the top and bottom of the ballast tank, that the complete tank capacity would need to be circulated every 5 minutes to compensate the heat loss to the ambient conditions, and this is most unlikely with such a system.

The complexity of the system, the problems of drainage of the air lines, the increased plant requirements, the dangers of possible pressurisation of the tanks, the limited extent of the benefits of the system, if any, and the need to provide additional freezing prevention measures make the system unsuitable for recommendation. A combination of this system and of water ballast heating pipes in the tanks would

not eliminate the problems associated with the air bubbler system nor seem economically justifiable.

2.4.2 Mechanical Agitation Systems

These are other variations of the circulation principle and similar considerations would apply as those already addressed. Submerged pumps at the bottom of each tank would provide the forced convection necessary and at considerably higher efficiency than air bubbling systems. Alternatively, agitation of the surface layers in the tank may be considered but such systems would only delay the onset of freezing. The quantity of heat transferred to the critical areas would be minimal, the largest contribution probably being the viscous friction of the agitator.

Intermittently operated submerged pumps combined with water ballast heating pipes in the tanks would need further study to judge their efficiency.

2.4.3 Insulation of Ballast Tanks

The most common method of reducing heat loss is to insulate the heat transfer surfaces. The prohibitive capital cost of such a provision, and the maintenance of the insulation throughout the life of the vessel does not recommend the system for this application.

3. BALLAST PIPING SYSTEMS IN SHIPS WORKING IN WINTER NAVIGATION

The ships ballast piping system with its piping runs, hangers, bellmouth suctions and valves is one of the greatest sources of operational difficulties in the field of winter navigation. The subject of valves is fully addressed in the following section.

Different types of ships have different characteristics and therefore different problems. We have divided our study into dry cargo carriers which may have several forms, tankers and finally specialized vessels.

3.1 Dry Cargo Carriers

This may be a bulk carrier, a self-unloading bulk carrier, a container ship or a Ro-Ro ship. To meet operational requirements these ships all require carrying ballast water when running in the light or ballast condition.

The problems of frozen ballast suctions, piping and valves are very frequent. They are as follows:

a. on deballasting, residual water freezes in ballast pipe lines and valves rendering them inoperable for future cycles
b. residual water freezes in and under bellmouth tank suctions causing a complete or partial failure of ability to fill or pump future ballast
c. failure of filled plastic ballast piping under freezing conditions
d. failure of gate valves due to design weakness allowing the entrained water to remain in the body of the valve and to freeze after deballasting.

3.1.1 Piping Systems

The solutions to these problems depend on the design chosen for the overall system. The piping systems presently in use and projected are described and commented on hereafter to properly identify the advantages and limitations of each system.

a. Manifold System

Probably the oldest ballast system in use is port and starboard ballast valve manifolds situated in the warm engine room under the direct care of the watch keeper. These manifolds lead to a separate pipe to each tank arranged to properly drain aft to the engine room cofferdam space directly below the ballast manifold where large radius elbows take pipes up to the manifolds. In this space it is relatively easy to remove the residual water from the pipes after deballasting or at lay up time via drain plugs or valves. In the event they were to be used on a regular basis the drain plugs can be made more readily

accessible, perhaps in a cofferdam beneath the ballast manifold and a compartment be fitted for ease of pumping out.

This system lends itself to the dry bulk carrier with large volumes in its ballast tanks allowing for the extensive runs of large piping. Its chief virtue lies in its ready draining ability with ballast valves in an accessible and frost-safe environment. The system allows the application of a low pressure steam connection to the manifolds to blow water out of the lines in low temperatures, or conversely the use of a positive displacement stripping pump or an eductor to remove the residual water in both pipelines and tanks.

It's defects are the large size and cost of the manifolds themselves and the several runs to each tank of large piping throughout the tanks. If these require extensive replacement or repair, large areas of the tank top must be removed and replaced to get at them.

b. Ring Main System

The ballast ring main system has several advantages, less cost being one of these, the ability to automate the system and the lower weight of the complete ballast system are others. The disadvantages lie with the fallibilities of the components especially under severe cold conditions. The non-operation of butterfly valves due to freezing in deballasted condition and serious damage to valve actuating equipment due to the immovability of the valve itself are caused for worry on the part of ships engineering staffs.

Duct Keel Arrangement

Another dry cargo vessel design may include the use of a duct keel in which a central ballast main might be fitted with actuator controlled valves in the duct keel with tail pipes into each double bottom ballast tank with the central main and valving to be heat traced, lagged and accessible.

This system has the advantage of keeping the ballast main and its valve arrangements in the dry and somewhat accessible. However, the ships structure cannot be altered too much in this very vulnerable area to allow for the large piping and valving envisaged for a laker type ship making short runs and requiring very quick cycling of ballast water. The system has found many applications in seagoing ships where speed of ballast handling is not so critical with consequently reduced sizing of piping and valves.

Submerged Valves in Adjoining Tanks

This design makes use of the ring main system of ballast piping with short leads of suction piping with actuator operated butterfly valves submerged and located in the tank immediately aft of the tank being pumped, the one most aft being located in the engine room. During ballasting, once the first tank is in ballast, the valve in that tank becomes submerged and if ever frozen, will become

operational after a short while and by back flushing if necessary. This system at least has the valve out of the tank which makes it possible to get at the valve for repair. It must as far as possible have the butterfly valve adjacent to the ring main to warm the valve as outlined later. The tail pipe must come off the ring main as close to the bottom of this pipe as possible and must be of short length with a rapid fall to the suction bellmouth to assure efficient drainage.

The system is not failproof under all conditions however, because the valves in empty adjacent tanks are prone to freeze at valve seat. This reduces the availity of working ballast and generally required that the ballast be pumped out successively, not selectively, which can make deballasting more complicated and can cost cargo deadweight due to the inability to load vessel the best way. It results in the tanks located forward having valves frozen shut, making it impossible to pump in during/after discharging.

Sefl-Unloader Tunnel Design

For the self-unloader, the ballast piping is designed to be a ring main in the working conveyor belt tunnel, located at the sides, clear of the unloading machinery but accessible for repairs, and capable of being efficiently heat traced, both pipe and valves and insulated against merely the ambient temperature of the tunnel. The suction branches lead off the ring main butterfly valves directly down into the tank below.

Following the design evolution indicated above, a new sea-going self-unloader has incorporated a longitudinal ballast tank under the central hopper, above the tank top in the vessel unloading machinery operating tunnel. This reduces the need for as much ballast capacity in the freeboard area as well as increasing the vessel operating range when the central ballast tank may be used for additional bunker tank capacity.

c. Striping Main System

The stripping main system consists in the use of a separate stripping main with separate suctions in each tank connected to a stripping pump of positive suction capabilities (e.g. screw or piston pump) to remove the residual water in the tank and piping system to a far greater extent than just the centrifugal ballast pump alone.

For a period, ballast piping design had abandoned the separate ballast stripping system as a costly addition. The thought was that the vacuum priming system would take over in the ballast mains to remove the last of the residual water in tanks and mains. However this has not been the case and the new buildings are now being fitted with stripping pump systems as described above and are found to be very effective. Of course the cost of the installation must be considered, but it is very time and labour saving in all conditions, especially so in severe freezing weather.

d. Ring and Stripping Mains to Circulate Machinery Cooling Water

The ring main system gives the ability to circulate the warmed raw water from the main and auxiliary machinery heat exchangers through the ballast ring main with discharge into the after double bottom tanks to be returned through the ballast stripping system to the machinery cooling sea bay in the engine room. This refinement ensures all inside recirculation of raw cooling water which at the same time assists in warming the individual ballast tank valves in the tanks during the loaded voyage when the tanks are dry and the tank valves have a tendency to freeze.

This system envisages the use of the ships ballast stripping piping and pump to return the raw water to the sea bay. Another variation has a separate discharge from the raw water pump to the after double bottom tanks only. Although effective, it defeats the purpose of warming the piping and valving of the ballast system. The use of the double bottom tanks as heat exchangers involves the loss of cubic carrying capacity but this may be a necessary condition of winter operation.

e. Piping to Separate Upper Side Tanks

The carriage of ballast water in tankage above the light load line is dictated by the design of seagoing bulk carriers and the use of these ballast tanks must be accompanied by means of keeping these somewhat isolated volumes of water from freezing. In such cases, the ships side ballast tank arrangement with the tanks above the light load line as separate tanks could be heated by use of recirculating the raw water warmed by the heat rejected from the ships machinery, the main engine exhaust waste heat or separately fired boilers. Refer to pages 14 and 15 for various possible piping arrangements. The cost of additional piping, valves, and draining arrangement will be high, however for a ship that is constantly operating in a freezing environment this solution may be applicable.

Separate piping systems for each of the ballast spaces could be installed but they would be expensive and more complex.

The provision of "drop valves" would be appropriate where upper side and lower side/double bottoms were adjacent.

3.1.2 Suction Line Bellmouths

The measures practised to alleviate freezing are to give the vessel a trim to keep any remnant water away from the suctions, the application of an anti-freeze solution to the location via the tank sounding pipes and circulation of warm sea water from the main engine coolers through the ballast main when such is the design. A heating coil or tracing placed at each bellmouth toe is the simplest, permanent and most efficient way of preventing last of the water from freezing. The heat transfer requirements are high in that area.

3.2 Tankers

These vessels show a wide range of diversification. From the ULCC and VLCC through all the size range of crude oil tankers with their fewer number of very large tanks, elaborate heating coil systems, inert gas systems, tank washing systems, cargo filling and pumping plants, some with separate submerged pumping arrangements for each cargo tank, through the refined products carriers to the specialty and industrial chemical tankers, they all require piping systems to handle their cargos and are designed to carry their ballast either in some of their cargo tanks or in dedicated ballast tanks.

The ballast systems in use consist in dedicated or cargo mains with the same piping, valves and pumping plants as are used for dry cargo except that tankers are generally fitted with gate valves for tightness of components and steel pipe only. Despite the best of equipment, their ballast cycle problems are often those of the dry cargo vessel compounded often by the inaccessability of the components caused by the non safe working conditions in tanks in the non-gas-free state.

The problems are basically the same as those of the dry cargo vessels:

a. removal of residual ballast water from tanks, piping and tank valves, whether ballast water is carried in cargo or dedicated tanks. The water freezes bursting gate valve bodies, sticking butterfly valves to their ring seats. Cargo suction lines have experienced freezing of lines passing through empty tanks.
b. water settling out from the cargo or remaining in the tank after cargo or ballast discharge freezes around the bellmouths and cargo cannot be pumped out or ballast pumped in. In product carriers, temperature of loaded cargo could well be in the 0°C to -6°C temperature range.

3.2.1 Piping System

The appropriate solution for the proper drainage of the tanker piping system is the use of a permanent low pressure steam connection into the cargo system manifold in the pump room to blow through the lines which induces a suction in the ballast suction lines and clears them of water. When there is trouble with the valves freezing either open or shut or with a line blocked by ice, the steam assists in making them operational again.

3.2.2 Suction Line Bellmouths

The same solutions described under Dry Cargo Carriers apply also here.

3.3 Special Service Ships

Ships in this class include icebreakers, ferries, tugs, navigational aid vessels, survey ships, etc. Although many of these vessels require to work in winter service in the ice, they do not have a requirement to carry ballast water to any extent, thus this problem is averted. Most ships have either a single or double pipe to each tank with the valves in the engine room and many are fitted to recirculate the main engine cooling water in the ballast tanks.

Some of the interviews carried during the study dealt with the exploration vessels in the Beaufort Sea. If service vessels are to be designed to operate for extended periods of time in very cold temperatures in the Beaufort Sea, they will have to incorporate a system of ballast water heating to retain full navigability at all times.

4. VALVES FOR MARINE USE IN FREEZING CONDITIONS

Although dealt with in general terms in the previous section under Ballast Piping Systems, valves are discussed in detail in this separate section for the reason that this single piece of equipment has been described as the most troublesome item by all concerned. Results of the questionnaire returns and the meetings with shipbuilders, operators and crews confirm the following conditions.

At present, valves for various system uses in freezing conditions have in most circumstances not been specifically designed for the job. This applies to ships operating in all Canadian waters in ice and cold weather conditions as well as in the Arctic.

The piping system designs presently applied to ice navigation ships show varying degrees of cold weather know-how and very little research into valve procurement for the optimum component. Further, the suppliers have not pursued the design of cold weather valves very far. True, valves for cryogenic systems are designed and readily available at a price; a price beyond the limit and of a quality too refined for ship ballast, hydraulics, machinery cooling and domestic requirements. The type and quality of valves required for ice navigation are not readily available.

The ships are built well to withstand the rigors of cold weather and ice navigation within their operating season in regards to strength and propulsive power but become too dependent on the skill and alert watchfulness of all crew members concerned to keep the ship moving about its business in cold weather and ice because of valve and piping problems.

First contacts with valve representatives led us to believe that some valve suppliers are concerned enough about the problem to have initiated R & D programs since much can be done to improve on shipboard valves, but after further contacts with 10 suppliers and manufacturers this proved not to be the case.

Firstly, the gate valve. To keep it from freezing in either the open or closed condition it must have better self draining capabilities to ensure the body itself is as dry as possible. Alternatively it can be jacketed to take steam or hot oil as a tracer to remove all risk of freezing, or the valve can be part of an integral electrical tracing or sealed and encased heating system. Thought may be given to inverting the valve and placing it horizontally to achieve better drainage. The metallurgy of the valve can be upgraded to make it more resistant to fracture from freezing expansion.

Secondly, the butterfly valve. This unit is an improvement over the gate valve because it is less costly and complicated, easier to arrange local actuation and eliminates the entrapped water with its

ice impairment of operation and damage common to the gate valve. To some extent this improvement is not without its own defects. During the construction of the ship, all too often the pipe fitting crews, unaware of the relatively delicate nature of these valves, force the piping runs into alignment with the valves thus distorting the circular shell of the valve. The result causes the spindle with its butterfly to become very stiff or inoperable. Under this condition the hydraulic actuator can soon shear the coupling or twist the valve spindle, still working the open or close lights on the ballast control panel with no actual operation taking place.

The valve seat and disc under the best of installation are often inefficient, anything but watertight; the seats often leak heavily between themselves and valve body.

Further, the valve has a bad tendency to freeze in the closed position when the pipeline is dewatered. This most common serious problem refers to the freezing of the seat against the circumference of the disc due to the normal dampness of the surrounding air, in which case heat has to be supplied to unfreeze the valve, or if ever the actuator is energized and the valve finally gets to open, the seat suffers damage, the more so the greater the number of recurrences. The manufacturer must consider among other changes a non porous surface material which, if appropriate under other design requirements, would reduce the amount of humidity retained on the seat and thus reduce frost accumulation. Perhaps the controls could include a position with the valve just cracked off its seat in the standby condition.

The "O" ring spindle packing wears rapidly requiring a complete dismantling to refit, this being a tedious and lengthy chore considering that ballast valves aboard ships are not always easily accessible.

Lastly, the actuator being an integral part of any remote control valve, the methods of valve actuation are worthy of study.

Higher than normal torques that are applied because of excessive pressure settings are causing damage to actuator or valve components. The atuator torque must be limited to the maximum operating value for which the valve is designed to operate under normal conditions. The torque unit must be better designed to sense the valve physical state and a remote control indicator must be incorporated in the ballast panel to relay the non opening or non closing of the valve when it is being activated under the design pressure.

The problems of winter navigation, in so far as valve operation is at present, are compounded by the difficulty of the crew in working to solve them under sub zero temperatures, knowing that a fast repair is urgently required if there is a full tank behind a stuck valve that may freeze rapidly and possibly delay the ship. Some of the problems described are not solely related to cold weather navigation conditions but are indicative of the concern associated with any mechanical or hydraulic problem that affects the ballast system of ships operating in difficult winter conditions.

The ways in which the valves can be improved are mentioned below but it will be a demanding project involving the designer, the supplier, the shipbuilder and the shipowner so that the running of the ship may be more efficient.

The ballast valve system must operate successfully in conditions of -50°C ambient temperature and foul and dirty ballast water at least for the 15 year life expectancy of the ships. At present, the valves supplied are not in this class. The valve sizes range from 15.2 cm. to 61 cm. in diameter.

4.1 Valve Specifications

A specification prepared by Intercan incorporating some of the improvements noted above and found necessary in service could contain the following.

4.1.1 Gate Valves

a. A change in design of the valve body to lessen the amount of residual water lying in the bottom of the valve body which freezes when the pipeline is dewatered preventing further opening or closing of the valve.

b. The valve to have a jacketed design, suitable for steam or hot oil to guard against freezing.

c. The valve to be arranged to fit an effective electric trace heating or a sealed and encased system in way of its vulnerable areas to guard against freezing.

d. The study of the metallurgy of the material of the valve to at least bring the valve up to the standard of the pipeline as regards strength against freezing. Presently, valve body is too easily fractured by included ice. The examination of the fracture always indicates the fragile nature of the design, totally unable to handle winter weather conditions. Stiffen up the design to be better able to handle the duties required.

4.1.2 Gate Valve Actuators

a. The use of pneumatic or electric actuators is not considered for the cold, wet and dirty conditions found in outside engine room services in winter navigation.

b. The hydraulic actuator must be robust, but its maximum torque kept within the allowable design stresses of the valve components and not attempt to operate beyond that torque. Provide range of normal operating torques required to operate valves to match the different valve diameters. It also must be able to report the non operational condition to the

operating panel, possibly by the provision of back-up switches on the valve stem independent of the actuator. See Figure 9.

c. The actuators must tie in well with remote operating rod gear (lazy rods) without operation of the hand gear when working hydraulically. See Figure 9.

4.1.3 Butterfly Valves

a. The body of the valve must be more rigid, better able to withstand some misalignment, perhaps even that caused by deflection of the ship due to different loading conditions. The valve must retain its concentricity to work at all. To avoid future trouble, the purchaser and fitter of the ballast system must be thoroughly instructed as to the need to preserve good pipe alignment at the time of system construction.

b. The sealing ring seat design to be rethought out. The seat must not be too soft or the disc beds into it, impeding reopening. At the same time it must not be too hard, or the disc does not make complete watertight contact. Select a material that will not be prone to water surface retention.

c. The design of the disc requires more thought as to shape. At present the disc, as it approaches the seat, does not fit simultaneously around its circumference. The fit is progressive and water tightness depends on the torque applied to press the disc into the seat. For the design, disregard the streamline shape of the disc and concentrate on achieving an efficient seal.

d. The spindle packing must be improved both in quality and in ease of repacking. The complete dismantling of the valve and actuator to accomplish same is unacceptable.

e. The design must be capable of inclusion of steam or hot oil jacketing or sealed and encased electrical heating system to prevent valves from freezing.

4.1.4 Butterfly Valve Actuators

a. The use of pneumatic or electric actuators is not considered for the cold, wet and dirty conditions found in outside engine room services in winter navigation.

b. The hydraulic actuator must be robust, but its maximum torque kept within the allowable design stresses of the valve components and not attempt to operate beyond that torque. Provide range of normal operating torques required to operate valves to match the different valve diameters. It also must be able to report the non operational condition to the operating panel, possibly by the provision of back-up switches

on the valve stem independent of the actuator.

c. Because of the tendency for the disc to freeze to the seat in the dewatered state, the actuator might allow for a valve cracked open position when on standby. The actuator might be made to assume this position automatically. Alternatively, the valve and its actuator might be somewhat over designed to break the ice seal around the disc.

All of the above noted deficiencies in both classes of valves are universal in operation. In an endeavour to ascertain from the valve manufacturers the possibility of the supply of valves with these conditions redesigned and corrected, these suggestions have been sent to several valve agents/distributors for furtherance to their manufacturers and to other manufacturers not covered in the first group. Canada, United States, England and Italy have been covered.

They were asked to comment on the subject and to say if they would consider the implementation of research and development programs to bring the products to a higher satisfactory standard. The cost estimate and the time before the improved products might become available were also asked.

Replies from the manufacturers themselves have not been numerous, two of them having had minimum exposure with their products in sub zero temperatures showed an interest and wished to pursue the matter further. Crane Canada Inc. and Process Piping Specialties are receptive to undertake R & D, each having a product development department. They consider that additional input and work on their part are required before they can arrive at a proper evaluation as to whether or not their products could meet the service conditions. The replies received from the agents/distributors for the most part described existing valves and actuators which do not match the above specifications. However, new seat designs have been incorporated in more recent valves and are said to improve watertightness.

5. PRODUCTS DESCRIPTION

The particulars of three groups of products, thermal fluids and ethylene glycol, electric heat tracing cables and piping insulation are described hereafter. These products are used to a limited extent with varying degree of success and are envisaged for retrofit and new vessel designs. The products if developed and fitted to meet the specific ship applications under study could become of wide benefit. For example it was found that the use of electric heat tracing is seldom designed properly as a system to integrate the necessary insulation.

5.1 Thermal Fluids and Ethylene Glycol

Thermal fluid heating systems have found application on board ships to heat cargo and for ship services such as pipe and valve tracing. Thermal heaters can be oil-fired and operated automatically and unattended, or installed to use the heat from the diesel exhaust gases. The systems operate at low pressures and require minimum maintenance. Petroleum and synthetic heat transfer fluids have good thermal and chemical stability, high specific heat valve, good viscosity index and are non-corrosive.

Low temperature petroleum base fluids have been developed to be pumpable at temperatures of -25°C to -30°C. To assure long oil life and freedom from insoluble material deposits most heat transfer oils have a recommended high temperature limit varying from 160°C to 315°C, depending on product type. When the high temperature conditions are not exceeded, the life of the charge can be from 20,000 to over 45,000 hours of service, based on product type, system design and operating conditions.

Synthetic chemical heat transfer fluids have lower viscosities and provide greater versatility in operating temperature over oil fluids. The temperature variation extends from a high temperature fluid operable up to 340°C to one that still remains liquid below -56°C.

When high temperatures are not needed, fresh water/ethylene glycol mixture is especially suited. Ethylene glycol thermofluid products contain anti corrosion inhibitors and stabilizers effective with most common metals such as carbon steel and copper. Galvanized pipe should not be used. The optimum fresh water/thermofluid ethylene glycol solution of 44% / 56% by weight gives freezing protection of -50°C, provides a homogeneus liquid and exhibits viscosity characteristics and heat transfer properties similar to water. Maximum heating temperature is limited to 65-75°C. Closed circuit systems non exposed to air and operated below the high temperature level will provide prolonged life of the fluid. A reinhibitor product is available to give extended life to the thermofluid without full recharge of the system. Water/ethylene glycol solutions have better

fluidity at low temperatures than thermal oils.

The price comparison between the three fluid types is the following, per litre:

		temperature range	
special petroleum oil	$1.60	-25°C	200°C
synthetic fluid	$5.50	-51°C	315°C
ethylene glycol	$1.30	-50°C	75°C

The price of the ethylene glycol is to be reduced by the proportion of water mixture. The premium paid for thermally stable fluids compensates for the marked advantage of operating at high temperatures and low pressures. However the ballast piping system does not require high temperature heating of the tracing fluid, a temperature maintained slightly above the water freezing point of say 5°C to 10°C would suffice to give protection, whereas the heating fluid must remain liquid at the low ambient temperature of -50°C when not in use due to possible intermittent requirements.

Compared with steam heating, a thermal fluid system eliminates the problem of freezing associated with the condensate from return lines. Used for the sole purpose of heat tracing of ballast lines and valves it would be expensive; but integrated in a larger system and for special ships such as tankers for heating cargo or ships that would operate in the Arctic for prolonged periods, it would be worth considering at the time of the design of a new ship for the heating of ballast lines and ballast water in the upper spaces.

5.2 Electric Heat Tracing Cables

Surface electric heat tracing cables are the most economical and easy to install of all the freeze protection tracing systems. They are used to a greater extent because of their simplicity and controlability. The tracers are flexible and lend themselves to spiralling around a pipe or valve or can be installed in parallel strips of various lengths. They provide long life, low maintenance service and can be fitted with watertight terminals. Their installation is approved for weatherproof conditions such as in tunnels but is not approved under submerged conditions which are those of ballast tanks.

Heat tracing design must take into consideration the thermal conductivity of plastic pipes which is much lower than carbon steel (0.12 vs 25.0).

One type of cable has a series of alloy resistance heating zones connected in parallel between the power bus wires at constant wattage. Another type is a continuous parallel circuitry designed as a self-regulating semi-conductive core heater which protects against over-heating by automatically increasing its heat output as the temperature decreases and vice versa. The polymer-carbon core enables the heater to vary its power output and to respond to temperature variations anywhere throughout the piping system. Both these types

can have a sheating construction of various materials such as a metallic copper or stainless steel braid shield or a fluoropolymer outer jacket. They can be cut to length at point of use.

There is also a tracing product which is constructed of a solid copper conductor insulated by a highly compressed mineral insulation and enclosed in either a copper or stainless steel tube sheating. The tough yet flexible cable can be bent to any shape, around the body of a valve or around bends in a pipe, and is absolutely waterproof. The cable is fabricated in standard or custom made lengths, pre-terminated and protected by a high density polyethylene jacket to prevent corrosion of the copper sheating in sea water.

The electric heating cables can be remotely controlled by a set of thermostats and controllers to maintain the pipe and valve system above the freezing temperature. The thermostatic controls ensure:

low running costs
no overheating of plastic pipes[1]
no overheating of the tracing elements themselves
flexibility of the system.

Heat transfer cement, which can be applied to fill the voids between the tracers and the pipe or valves thus forming a continuous thermal bond between the two, is not recommended due to the low temperature of the intended use.

5.3 Piping Insulation

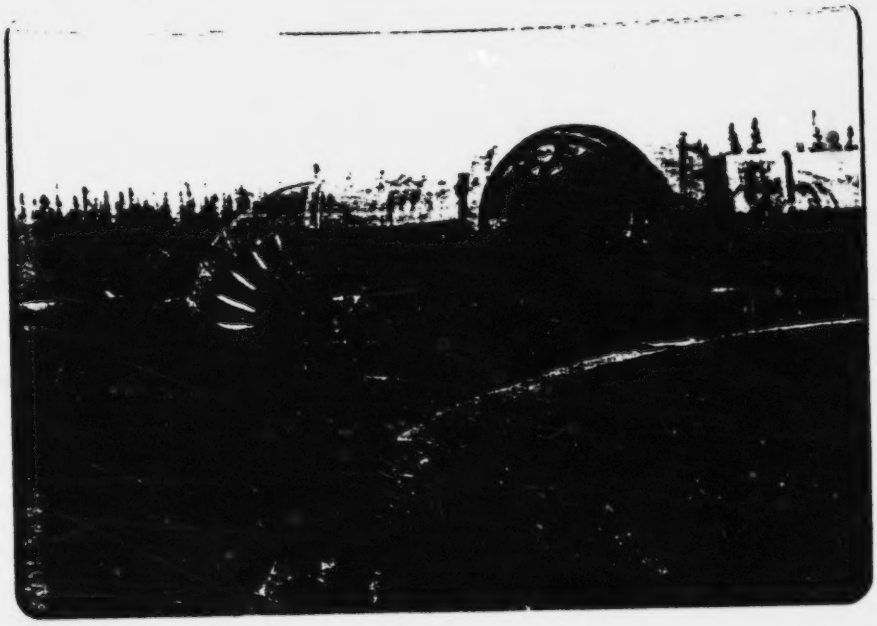
To be effective heat tracers should be insulated. This is of necessity with electric external tracers. The insulation at the same time provides an economical operation. Numerous enquiries have been made to Canadian and foreign companies to find a product that would be fully waterproof for installations in submerged conditions.

One Canadian company uses a proven technique for factory or site applied installations of insulation protection of piping and valves traced with electric heat systems. The insulation material is a rigid poly-urethane foam applied either bonded or non bonded directly to the entire pipe and valves surfaces. See illustration. The closed cell (90%) structure provides low thermal conductivity but also an extremely low moisture and vapor permeability and a high resistance to water absorption. It has excellent dimensional stability, high strength and low density. Subsequent to the foaming process, a wrapping of high density black polyethylene protective outer jacket is applied. The jacket is applied hot at 48°C in multiple counterwound and overlapping layers. The method ensures maximum bond to the foam insulation and provides a shrink tightened, waterproof, and mechanically strong membrane. The imperviousness of the construction under full water head is unknown and needs to be tested. It is

1 Surface thermostats must always be used on plastic pipes.

highly satisfactory for tunnel and other dry compartment applications. The insulation design is adaptable to any type of electric heat tracing systems. The tracing and control systems can be pulled through pre-installed conduits under the insulation or covered with a heat transfer cement or heat conducting tape to prevent the foam insulation from entering underneath the cable.

Other well known products, in particular fibreglass for its fire resistant properties, have good insulating properties but their physical structure, being not of the closed cell type, makes them vulnerable to moisture or water. Fabricated rigid cylindrical sections for pipe insulation or mats for valve insulation can be provided with a tough protection jacket, which consists of fibreglass fabric bonded to an aluminium vapour barrier. This construction is ideal for runs located in dry tunnels. Longitudinal and circumferential joints have to be sealed.



6. ICE INGESTION OF SEA WATER INLETS

The conventional method of cooling ships machinery is to reject heat to the sea water. This involves drawing water into the ship, circulating the machinery components of heat exchangers, and discharging the water at the ship's side. The water enters the ship's hull through sea inlets low down in the vessel usually adjacent to the turn of the bilge or in the bottom plating to prevent ingress of surface ice and debris. A perforated plate or grid is fitted over the opening to limit the size of any debris which may be drawn in. The majority of variable draft vessels are also provided with a sea inlet higher up the ship side for use in shallow waters to limit the ingress of mud and sand. In freezing conditions the problem of ice ingress through the sea inlets causes blockages resulting in loss of cooling water flow and over heating of machinery components.

The extent of the problem varies according to the draft of the vessels, the type of ice encountered and the areas of operation. Relatively shallow draft vessels such as supply boats, tugs and ferries which operate in the Beaufort Sea and St. Lawrence River are affected to the largest extent due to the proximity of the sea inlets to the surface of the water or ice. The larger carriers of the Lakes and Gulf of St. Lawrence advise occasional problems at lighter draughts.

The type of ice which gives by far the most problems is frazil and slush ice which forms in the upper layers of the water. The crystals are disturbed by the passage of ships and become distributed to depths which reach the ballast draught of the larger vessels at around 5 metres. For the tugs and supply boats, choking of the sea inlets often occurs particularly in shallow water and the operating schedules of the vessels are affected in varying degrees. For the Beaufort Sea operators the problem tends to dissapear after the frazil ice has frozen to hard first year ice. The length of time that the condition exists varies with the weather conditions but periods of one-two weeks at the end of the season are not uncommon. The severity of the problem is influenced by the sea inlet system arrangement and older vessels are more prone to congestion than newer vessels which have more congestion prevention measures fitted.

All the vessels have single ice strainers fitted inside the hull adjacent to port and starboard main sea inlet boxes. As the strainers usually become blocked before the sea boxes a manual clearing operation has to be carried out with valved isolation of the strainer. Sea water cooling is maintained meanwhile through the second sea box.

During the worst conditions of slush and frazil ice, cooling water flow can only be maintained for short periods of time in shallow draft vessels before a repeat of the clearing operation has to be carried out. Where congestion affects the main sea boxes the use of

low pressure steam through dedicated connections assists in the clearing operation. A case however was reported where the sea inlets of one large vessel became blocked in the Gulf of St. Lawrence and the vessel drifted for one hour without engine power before the blockage was cleared.

Problems have also been experienced with the blockage of sea suctions separate from the main sea inlet boxes, auxiliary engine cooling and ballast water inlets being examples. The latter example involved ballasting operations of some tankers in the St. Lawrence River when slush and frazil ice conditions prevailed. Partial ballast was taken on at the berth and continued after departing into the river, where blockages of the separate ballast suction were experienced. Under these weather conditions the vessels now take on full ballast at the berth maintaining a trim by the stern to keep the suction openings as deep in the water as possible. This procedure has eliminated the problem.

Modern design now tends to limit the number of sea inlets so that ice control and prevention measures can be centralized.

One solution to the problem is the provision of reversing the flow through the sea box whereby a "sea inlet" becomes an overboard discharge, and the ice is flushed out. This principle is used on the Canadian Government ice breaker "Louis St-Laurent".

The most common method of controlling ice build up in the sea inlets is to use the heat of the machinery cooling system by recirculation of the cooling water to the sea inlet. In this way the rejected heat melts any ice collected in the inlet and the quantity of water/ice drawn into the vessel from the sea through the grillage is reduced to only that amount pumped overboard to maintain machinery system temperatures. This method has almost universal application at the present time, is a requirement of the regulatory bodies for ice class ships and undoubtedly plays the most significant role in reducing the problem. A difference in practice exists as to the position at which the recirculated water is fed back into the suction system. Return to the sea box, return between the sea box and the inboard ice strainer, and in a few cases return to the sea bay are all in use. No conclusive information has been found as to the most efficient position, but it is considered that return to the sea box would achieve the maximum effect for vessels with large grid intake quantities.

Older vessels were designed with two sea boxes only, one on each side of the engine room and the sea water pumps drew suction directly from either side. Modern practice in ice capable ships is to provide a double bottom sea bay athwart ship between the port and starboard sea boxes of large capacity to allow separation of any ice crystals to take place. Sea bay widths of up to 4 frame spaces and capacities up to 60 tonnes have been used. Sea water discharges from each of the sea boxes through isolating valves and strainer to the sea bay through large diameter pipes. The machinery space sea water pumps have separate suctions from the sea bays only, through heavy gauge

tailpipes extending down some 70% into the bay. Tailpipes are also fitted to the suctions from the sea boxes and as the ice drawn into the box floats to the top of the box the tailpipe suctions are left relatively ice free. The same action should also take place with any ice which finds its way into the sea bay, where melting of the ice is aided by the heat transferred through the upper structure of the bay from the adjacent engine room space. The ice collecting in the sea boxes normally melts under the influence of the heated recirculation water but cases have been experienced where ejaculation of ice takes place from the sea box air pipes onto the open deck in some of the smaller vessels. The use of large diameter air pipes in this application would aid the removal of ice congestion particularly as these pipes pass up through the heated engine room spaces and diameter greater than 15 cm. would not seem unreasonable.

The suction effect from pumps pulling water through the sea box grillage assists the intake of ice particles, and this is influenced by the flow velocity.

The grillage on open water vessels usually has a grid/port area ratio something over 2:1 whereas with vessels for ice navigation the ratio is normally about 6:1, with grill discrete aperture sizes in the region of 12 mm. to 20 mm. Suction port areas from the sea box are based on the maximum flow rates of the pumps being served and water velocities, with flow velocities of 2 m./sec. being commonly used for this application. Although there is no known experimental data about the influence of flow velocity on the entrainment of ice particles into sea suction grillages, it is considered that decreasing the velocity will reduce the suction effect and this may be achieved by increasing the grid/port area ratio. Values of 8-9:1 have been suggested by some authorities.

For cold climate operation the necessity of using an open machinery cooling cycle with heat rejection directly to the sea water must be closely questioned. The heating requirements of the vessel and the cooling requirements of the machinery should be carefully evaluated and the maximum use made of machinery heat rejection cycles within the vessel if additional primary fuel energy is to be conserved. The aim of the heat transfer systems should be to keep the maximum amount of heat onboard the vessel, and where rejection is inevitable this should be effected at the lowest possible temperature.

The effects of such a design on sea box operation are that minimal sea water exchange will take place between the vessel and the sea and in consequence very little ice will be indrawn. A closed loop main engine sea water cooling system using the ballast tanks of the vessel as heat exchangers is one of the more obvious and commonly employed methods of dissipating machinery rejected heat.

In the case of the M.V. "ARCTIC", using internal circulation through the ring ballast main only as the closed loop, it is estimated from calculation that the heat to be removed from the main engine piston/jacket, hub oil, and scavenge air coolers, being of the order

of 26% of engine fuel energy, would be dissipated to the ballast tanks if a temperature difference of 35°C existed between the cooling water inlet to the tanks and the ballast water temperature at a main engine power of 85% MCR. With a ballast temperature of 0°C this means that the main engine coolers would have to operate with secondary cooling water temperatures in the range 36°C to 53°C. Although these temperatures are higher than even tropical operation, the example illustrates the possibilities of this simple system. If the surface area of the ballast main was extended to double the area previously considered, then the cooling water temperatures would be in the range 14°C to 30°C for the same conditions. These are normal cooling water temperatures for vessels with operations in temperate climates. However, for cold climate operation the requirements for supplying heat for the prevention of ice formation in the ballast tanks must also be considered, and in this connection Section 2 is relevant.

Such a system however is inoperable for loaded voyages when no ballast water is carried, and also for vessels with relatively small ballast capacities. A partial solution to this problem would be to have dedicated tanks for machinery cooling purposes in lieu of the athwart ship sea bay. The main machinery salt water cooling pumps would take suction from these tanks and discharge back to the tanks. Temperature control would be affected by a branch discharge line overboard, and the only water drawn into the vessel would be to replace that discharged through the overboard branch. Such a system has the advantage of use only when required, intake water is reduced to that quantity required to maintain tank temperature and one or more of the ballast tanks of the vessel may be used for this purpose. The system has found favour with some operators mainly in the retrofit capacity.

The major disadvantage of the system is loss of deadweight or increased ship dimensions but the safety of the vessel through maintenance of main engine power has overriding priority. A provision may be made to indirectly supply heat to the sea boxes for control of any ice which may be indrawn with the reduced intake quantities. A single loop in the cooling recirculation line through the top of the sea box could be considered.

Sea boxes fitted in the majority of vessels occupy two or three frame spaces at the turn of the bilge in the machinery spaces. The volume and geometry of the box is influenced by the capacity of the pumps being served, ice collection and separation considerations, and cost effective construction methods. Modern practices are taking increased account of the ice separation and collection considerations.

Extending the height of the sea box increases the volume of the box, increases the dwell time of the sea water in the box and aids the separation of the ice particles which float to the top due to their lower density. The entrainment of the ice in the water flow is influenced by the velocity of flow through the box and the structural protrusion inside the box. As turbulence is detrimental to the efficiency of ice separation, the methods of plate stiffening in this

area should be carefully considered to avoid the creation of eddies and vortices and where possible the stiffening should be external to the box. Reductions in flow velocities will be achieved by reducing intake requirements and increasing flow area. To aid the separation of the ice particles sea boxes fitted with weirs are now becoming standard practice. With this arrangement the water enters the bottom of the box into a first chamber and has to flow up and over a weir to reach the suction port in the bottom of a second chamber. Any indrawn ice is thus force circulated to the top of the sea box.

Once the ice has been separated from the intake water the problem remains of how to clear it. The provision of direct steam clearing or indirect oil heating may be used. Alternatively, the sea box air pipe could be replaced by a large diameter heavy gauge pipe terminating at the ship side clear of the load water line. The buoyancy forces of entrained air and entrapped ice will assist the discharge of the ice through the pipe. The further provision of an ice screw pump fitted in the pipe could be considered in severe cases for the mechanical discharge of accumulated ice.

Figure 10 shows a sea box arrangement incorporating a weir arrangement, large diameter vent pipes, recirculation of cooling water to the sea box inlet, extended tailpipes and duplex ice strainers.

In summary the prevention measures for alleviating the problem of ice congestion in sea inlet boxes are:

a. recirculation of cooling water
b. decreased flow velocities through increased grillage areas and sea inlet box cross sectional areas
c. minimal sea water intake volumes by cooling water heat exchange inside hull
d. provision of weirs for ice separation
e. extended tailpipes
f. increased area of vent pipes
g. use of low pressure steam clearing
h. provision of reverse circulation
i. two separate sea inlet boxes only, one port, one starboard
j. provision of heating coils in ice collection areas
k. use of screw pumps for discharge of accumulated ice
l. top openings of sea boxes to ship side above LWL
m. use of conventional dedicated sea bays
n. use of ballast spaces for cooling water heat rejection.

The combination in which these measures are used is dependent on the operating profile of the vessel and its working draft, both of which are major contributors to the problem. At the present time few problems exist with deep draught vessels with the measures a, e, i, m provided, and the problem is only severe in shallow draft vessels over short defined periods of their operating season. As cold climate operations are extended and operating profiles change, the problem could be more severe, in that case the adoption of an increased number of the above measures may become more cost effective.

7. AREAS OF RESEARCH AND DEVELOPMENT

The numerous contacts the study team members had with various persons directly involved with ship design and operation, plus the own experience of the team members showed that ballast systems of ships operating in winter conditions are not always given as much attention at the time of the design of a new ship as is given to other major components or systems, and even when they are, when problems do occur, they are left in the hands of the operators.

There are two areas which have repeatedly been brought to the attention of the team members.

7.1 Designs of Systems and Components

They relate to the location and shape of ballast tanks, ballast water heating, declivity, type and lay out of piping, heating of piping and valves, valve quality, drainage system, sea water intakes, etc.

7.2 Products or Components Unsuitable for the Intended Application

These are products that have not been originally designed for the particular cold weather environment for which they are used and give unsatisfactory results, or products not being utilized because it is known that they would not perform as required. Valves fall in the first category, electric heat tracing and insulation in the second.

7.3 Identification of Areas for Research and Development

Specific subjects related to the two previous headings have been identified.

7.3.1 Tanks

The entire ballast tanks design should be addressed further to undertake research on various alternative designs of tanks commensurate with ship stability and use. Specialized ships or those contemplated for prolonged periods of navigation in a cold weather environment should be studied and analysed to determine the possibility that no ballast be carried above the water line or, if carried, it be in separate tanks.

7.3.2 Temperature Patterns

Under the latter options of the separate tanks, research is required to establish the parameters of the sea water/hull/ambient external, hold and ballast water temperatures affecting the calculation of the heat transfer coefficients for the design of any ballast water heating system.

7.3.3 Water Circulation

Circulation of ballast water has been discussed frequently during the course of the study in view of circulating the cold water in the exposed upper spaces of the tanks by marginally warmer bottom layer water within the tanks themselves or alternatively the partial pumping out of the cold water in the exposed upper spaces and its replacement by warmer water found at the depth of the sea water intake. If it is found that the heat content of the recirculating or sea water is enough to prevent the ballast water from freezing, a remote control recirculation/pumping program that would meet the stability criteria of the ship would find an application for those vessels that do not operate for prolonged periods of time in cold weather conditions, either in early spring but more so in late fall before lay up time.

7.3.4 Gate and Butterfly Valves

The following points have a large bearing on the efficient functioning of valves:

- design improvement to gate valves to eliminate body fracture when subjected to the stress caused by the freezing of the residual water entrapped at the bottom of the gate pocket.

- design of an encased electric heating element within the body of valves to prevent freezing of the discs against the seats in butterfly valves and of the residual water lying at the bottom of gate and butterfly valves.

- design of sealing materials that remain flexible and pliable at -50°C to -60°C temperatures, yet durable. Some materials presently in use are effective at -30°C only.

- sample valves need to be tested in a cold chamber to test the effect of the remnant water in the gate pocket of gate valves, frost formation between seat and disc on various materials used in butterfly valves and maximum torque required to brake the ice ring.

7.3.5 Electric Heat Tracing Systems for Use in Submerged Tanks

The design of an electric heat tracing installation of a system submerged in a tank needs to be developed in order to obtain approval from the classification societies. Each single electric heat tracing circuit could be designed to have its terminals located in a dry junction box.

7.3.6 Insulation Used for Submerged Pipe and Valve Systems

The properties of the insulation product and of the complete installation have to be tested for sustained periods of time under a head of water to ascertain their imperviousness. Should the test prove unsuccessful, research would be required to develop an economical, resistant and flexible jacket material suited for the service.

8. CONCLUSIONS

The conclusions are devised to apply to general topics but are related as much as possible to problem areas and more specifically to their solutions. The section gives existing solutions and proposes variations of these, or new ones to the partial or full elimination of the problems, depending on the extent of their application.

8.1 Overview

Problems are numerous, but only a few are of large magnitude. Solutions pertain to measures that involve:

design
operating procedures
products improvement.

The effects of ballast water freezing have not been severe enough to warrant major design changes or additional capital expenditures due to the present operating profiles of Canadian vessels. This situation is changing slightly as more vessels operate over an extended season in the Beaufort Sea, St. Lawrence River and Great Lakes. In these circumstances ships have to be fitted accordingly, but of greater importance are the vessels which will be exposed to more arduous conditions. This forces those involved to adopt designs and choose systems and products which will provide more reliable and trouble free ballast systems.

An attempt was made to suggest a preferred system among those described in the study for ships navigating in prolonged - 40°C conditions but this proved not possible without detail designs of each type of ship, whether it be for standard ships or specialized ones like the M.V. "ARCTIC".

8.2 Geographical Survey of Ballast Water Freezing

The problems of the St. Lawrence River and Great Lakes bulk ship operators are more severe than those of any of the other operators interviewed or surveyed by questionnaires. The operators in the Eastern Seaboard are the least affected. Those in the eastern Arctic and Beaufort Sea have not yet experienced the full impact of the problems because their limited period of operation has been only from June through November.

8.3 Tanks

8.3.1 Problems

Ice forms in the ballast tanks of ships in cold climate conditions particularly where ballast water is carried in side tanks above the water line and in topside tanks. The ice forms initially on the free surface of the water followed by the tank structure boundaries above the water line and exposed to the ambient air

conditions.

The severity of ice build up is dependent on the operating profile of the ships. The majority of the occurrences cause many problems, viz loss of deadweight, ship delays, cost of ice removal, repairs of components, whereas the very severe remote cases cause damage to the structure of the tanks. The problems are contained at the present time and not universal among owners.

8.3.2 Solutions

a. Existing Operating Procedures and Designs

Operating procedures devised for each ship and minor design changes appear to cope with the problems of the ice formation and of its consequential results. The problems do not seem to be severe enough to justify major design changes or capital expenditures. The existing procedures and designs are obviously unsuitable for prolonged exposures and more permanent methods will be needed.

b. Future Designs

New designs are to require that greater importance be given to the elimination of exposed tanks above the water line level, particularly for vessels of prolonged exposures in cold climates. If ballast must be carried above the water line, improved designs will be achieved by considering:

a. utilization of low grade heat
b. utilization of waste heat rejected from machinery
c. supplying heat quantities to counter the losses to ambient air only, as attempts to raise the ballast water temperature above the sea water temperature is wasteful and expensive
d. limitation of ballast quantities to which heat must be supplied.

Separation of upper tanks from lower side and double bottom tanks would physically limit the spaces in this regard.

Recuperation of waste heat from the main engine exhaust and cooling water which may otherwise be lost to the atmosphere is economically very attractive but to prevent freezing in low temperature conditions, additional heat from a separately fired steam, hot water or thermal oil boiler is required. The cost of the fuel is considerable. It would cost per day approximately $1,200.00 to $1,900.00 of additional fuel per vessel for a system used in conjunction with the heat recuperation from the main engine cooling water only, against $1,800.00 to $4,500.00 otherwise. These figures, based on marine diesel oil at $C 360/tonne, apply to typical Canadian vessels, of which three have been chosen for the study, the M.V. "ARCTIC" and two laker vessels. To the fuel cost must be added the capital and maintenance costs.

The means of heat transfer are to pump the ballast water to the heating element by dual piping circuits through and to each of the ballast spaces to be heated, or by circulating the ballast tanks in series, on and over-flow principle; alternatively, to circulate the heating fluids in the ballast spaces by the use of heating pipes in the tanks such as the ballast ring main, or preferably by dedicated heating pipes in the spaces of the upper side tanks exposed to the ambient air.

The application of this solution depends heavily on the operating profile of the vessel for economic viability, and each application would need careful assessment.

The regular crew should suffice to provide the necessary attention regarding the heating and level of ballast in the tanks and the operating procedures noted in the report.

Other solutions originating from different concepts have been investigated:

- the provision of an air bubbler system within the ballast tanks or of submerged pumps at the bottom of each tank as a means of insuring circulation of water within the ballast tanks are not considered suitable as it is evaluated that the heat transferred to the critical areas would be minimal;
- insulation of ballast tanks to reduce heat losses is discarded as it would be prohibitive.

8.4 Piping Systems and Valves

8.4.1 Problems

Dry cargo carriers and tankers experience frequent and recurrent freezing problems of ballast suctions, piping and valves. On deballasting, residual water freezes in pipelines, valves and bellmouth suction toes. Plastic pipes burst when left filled with water.

Gate and butterfly valves are critical parts in a ballast system and due to the conditions of residual water and normal dampness of the surrounding air they are prone to freezing, thus creating the greatest problems of all those experienced by the operators. Frequent cases occur where gate valves burst and butterfly valves have their disc stick to the seal ring. The numerous contacts made with the agents/distributors and manufacturers have shown that the valves sold for ballast service are of the general industrial type not designed specifically for the dewatered state in an unprotected cold ship application.

8.4.2 Solutions

A solution that helps to minimize the residual water left in the tanks, piping and valves is a separate stripping main system in

conjunction with the ring main system. This offers positive suction capabilities. Both mains give the ability to circulate the warmed raw water from the main and auxiliary machinery heat exchangers through the ballast ring main. Discharge being effected into the after double bottom tanks and being returned through the ballast stripping system to the machinery cooling sea bay in the engine room. This refinement assists in warming the individual ballast tank valves in the tanks during the loaded voyage when the tanks are dry.

Eductor stripping of ballast lines is becoming common practice as an improved added method of suction.

The solution in the case of separate upper side tanks for certain specialized ships that operate for long periods of time under a sustained low freezing environment is to provide heat by a separate pipe loop or series of loops. These passing through the upper spaces of the side tanks and being located above the water line level for maximum effect.

The two best solutions to the valve problems are to install a manifold system or to run a ring main in those vessels designed with a duct keel or tunnel. In this latter case, heat tracing and insulation become a requirement.

Further concerted efforts are urgently needed to provide valve and actuator designs that will give satisfactory results. A specification for the two types of valves and actuators has been prepared to guide the valve manufacturers develop better quality products.

Barring other solutions, the solution that encompasses all the problems of frozen lines, valves and bellmouth suctions is a heat tracing system protected by insulation. A properly designed electric heat tracing system is the most efficient, economical, versatile and simple installation to use. Heat tracing systems need to be insulated if they are to give meaningful results.

8.5 Sea Water Inlets

8.5.1 Problem

Ice ingestion affecting the main sea boxes is predominant when the cold climate conditions favor the formation of frazil and slush ice, a problem which prevails in the Beaufort Sea, St. Lawrence River and Gulf and Great Lakes. The length of time that the conditions exist is dependent upon the weather.

8.5.2 Solutions

The most common method of controlling blockage by ice is by the recirculation of the machinery cooling water directly into the sea inlet.

A closed loop main engine sea water system using the ballast tanks as heat exchangers is a solution that eliminates completely the problem. In the case of loaded voyages when no ballast is carried and for vessels with relatively small ballast capacities, a partial solution is to have dedicated tanks. They have the advantage of being used only when required and the intake water is reduced to that quantity required to maintain tank temperature. A provision can be made to indirectly supply heat to the sea boxes for control of any ice which may be indrawn with the reduced intake quantities.

Low pressure steam clearing through dedicated connections is particularly adapted to tankers and icebreakers.

Other solutions relate to ice segregation to help in the prevention of clogging. Construction methods to that effect can take the form of double bottom sea bay athwart ship between the port and starboard sea boxes of large capacity, sea boxes fitted with weirs, extended tailpipes and increased areas of vent pipes.

8.6 Areas of Research and Development

Continuous research and development are required to improve the efficiency of ballast systems and components of ships navigating in cold weather conditions, particularly in the designs of systems and components and in products or components found unsuitable for the intended application.

9. RECOMMENDATIONS

9.1 Design of Ballast Systems

Designers, shipbuilders, shipowners and operators should devote their best effort during the planning stage of a vessel so that design work of ballast systems and procurement of components be considered as important and vulnerable to operational deficiencies as are other major systems found in ships.

Tanks

New designs for vessels with prolonged cold climate operations should attempt to limit the ballast below the water line and set that aim as one of the major design parameters. If ballast must be carried above the water line, the design should aim at separating the upper tanks from lower side and double bottom tanks to physically limit the spaces.

Designs of separate upper side tanks for certain specialized ships should incorporate separate heat pipes passing through the upper spaces of the tanks for maximum efficiency.

Other solutions originating from different concepts have been investigated:

- the provision of an air bubbler system within the ballast tanks or of submerged pumps at the bottom of each tank as a means of insuring circulation of water within the ballast tanks are not considered suitable as it is evaluated that the heat transferred to the critical areas would be minimal;
- insulation of ballast tanks to reduce heat losses is discarded as it would be prohibitive.

Heating Systems

Recuperation of waste heat from the main engine exhaust and cooling water which may otherwise be lost to the atmosphere is economically very attractive and should be given high consideration. To prevent freezing in low temperature conditions, additional heat from a separately fired steam, hot water or thermal oil boiler should be provided if proven economically justifiable.

Installation of a properly designed electric heat tracing system to prevent freezing of lines, valves and bellmouth suctions would prove to be efficient, economical, versatile and simple.

Piping Systems

Designs to remove residual water left in tanks, piping and valves should consider a separate stripping main system or an eductor, where compatible with other systems.

Valves

Vessel designs should consider a manifold system or ring main in those vessels designed with a duct keel or tunnel to lessen valve problems.

Valve manufacturers should make use of the specifications prepared for the two types of valves and actuators as a guide to develop better quality products.

9.2 Operating Procedures

The following operating procedures should be used for particular situations and relatively short voyages to help prevent water freezing: partial pump out and refill intermittently, continuous circulation, reduction of water level to vessel water line, change of fresh water for salt water and complete drainage.

Operating procedures applicable to each ship design should be drawn-up for the benefit of ship's crew for various ballast operating methods, including winter lay up.

9.3 Sea Water Inlets

Proven methods should be used to cope with ice ingestion in main sea boxes. They are:

a closed loop main engine sea water system using the ballast tanks or dedicated tanks as heat exchangers,
low pressure steam clearing through dedicated connections,
ice segregation by appropriate construction methods.

9.4 Areas of Research and Development

Designs must be developed and products need to be enhanced in order to eliminate or lessen the problems associated with ballast freezing. The following areas have been identified.

a. Tanks:
determine if no ballast can be carried above the water line for certain types of ships, or, if carried, it be in segregated tanks.
b. Temperature Patterns:
establish the parameters of water, hull and ambient air temperatures for the calculation of heat transfer coefficients.
c. Water Circulation:
measure the temperatures of ballast and sea water to determine their heat content and possible circulation within the tanks.
d. Gate and Butterfly Valves:
design new gate valve bodies and butterfly valve sealing materials and test sample valves in laboratory.

e. Electric Heat Tracing:
   design electric heat tracing circuit for submerged application.
f. Insulation:
   Test insulation under a head of water.

FIGURES

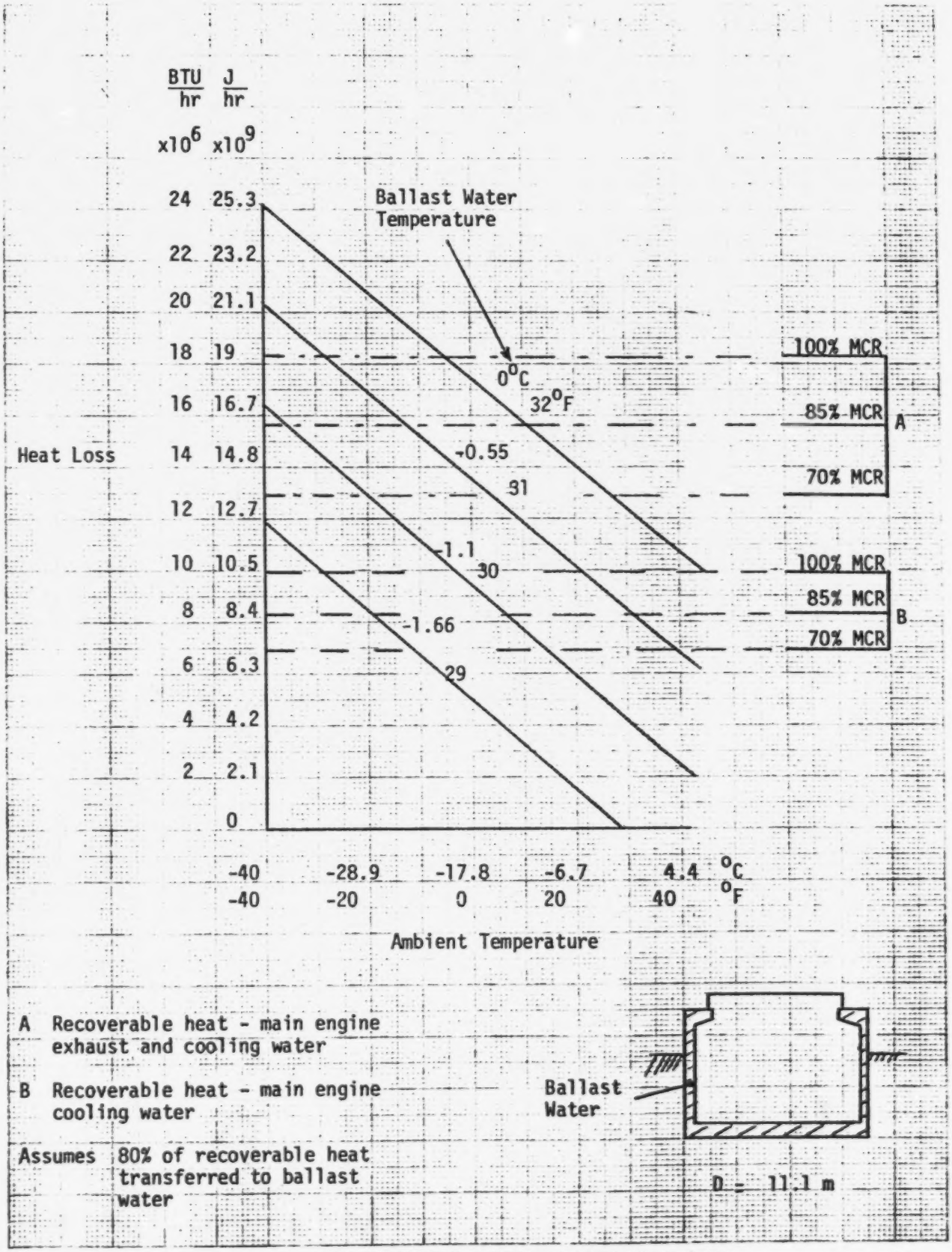


Figure 1 M.V. "ARCTIC" - Ballast Tank Heat Loss

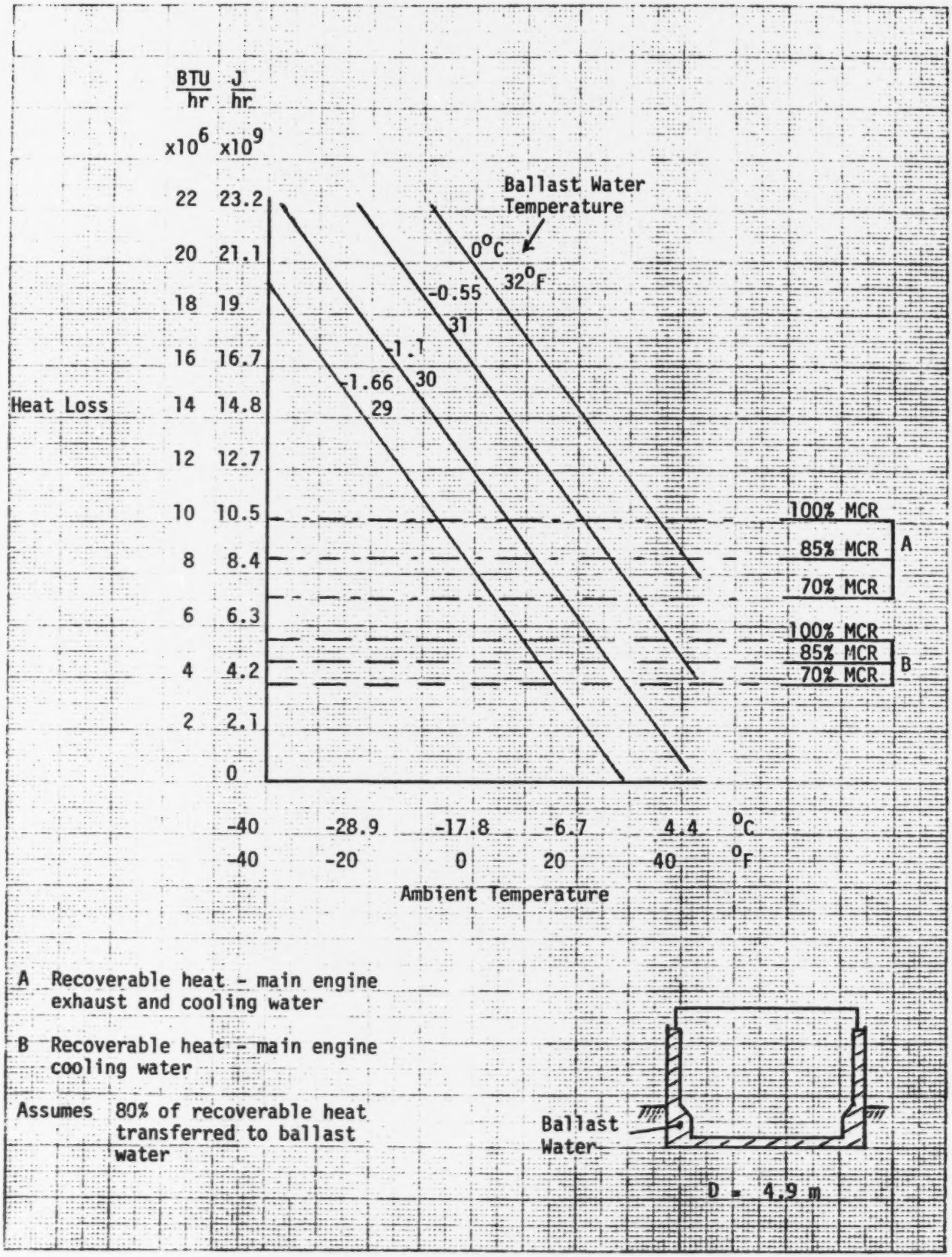


Figure 2 GL1 - Ballast Tank Heat Loss

10 MM/CM

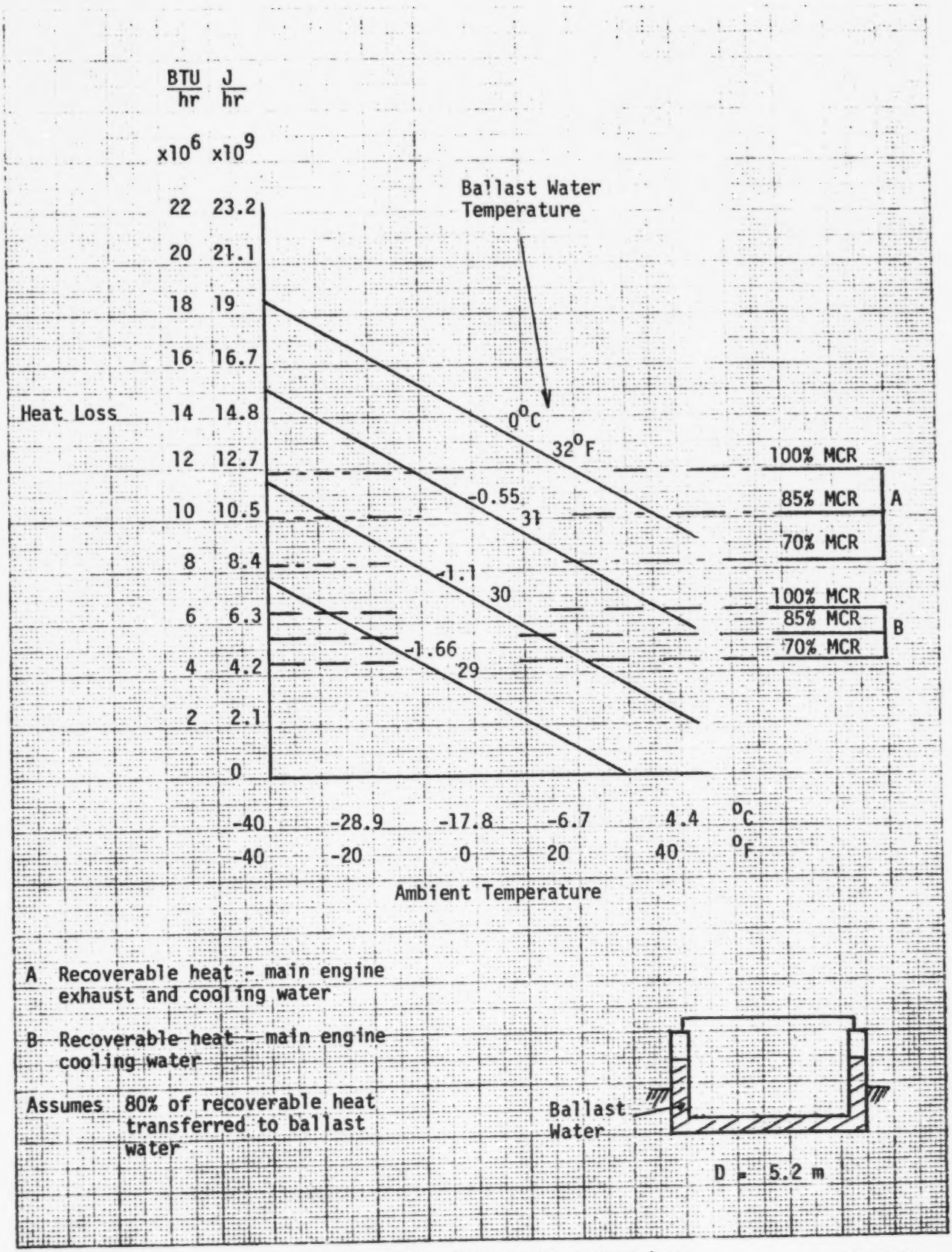


Figure 3 GL2 - Ballast Tank Heat Loss

10 MM/CM

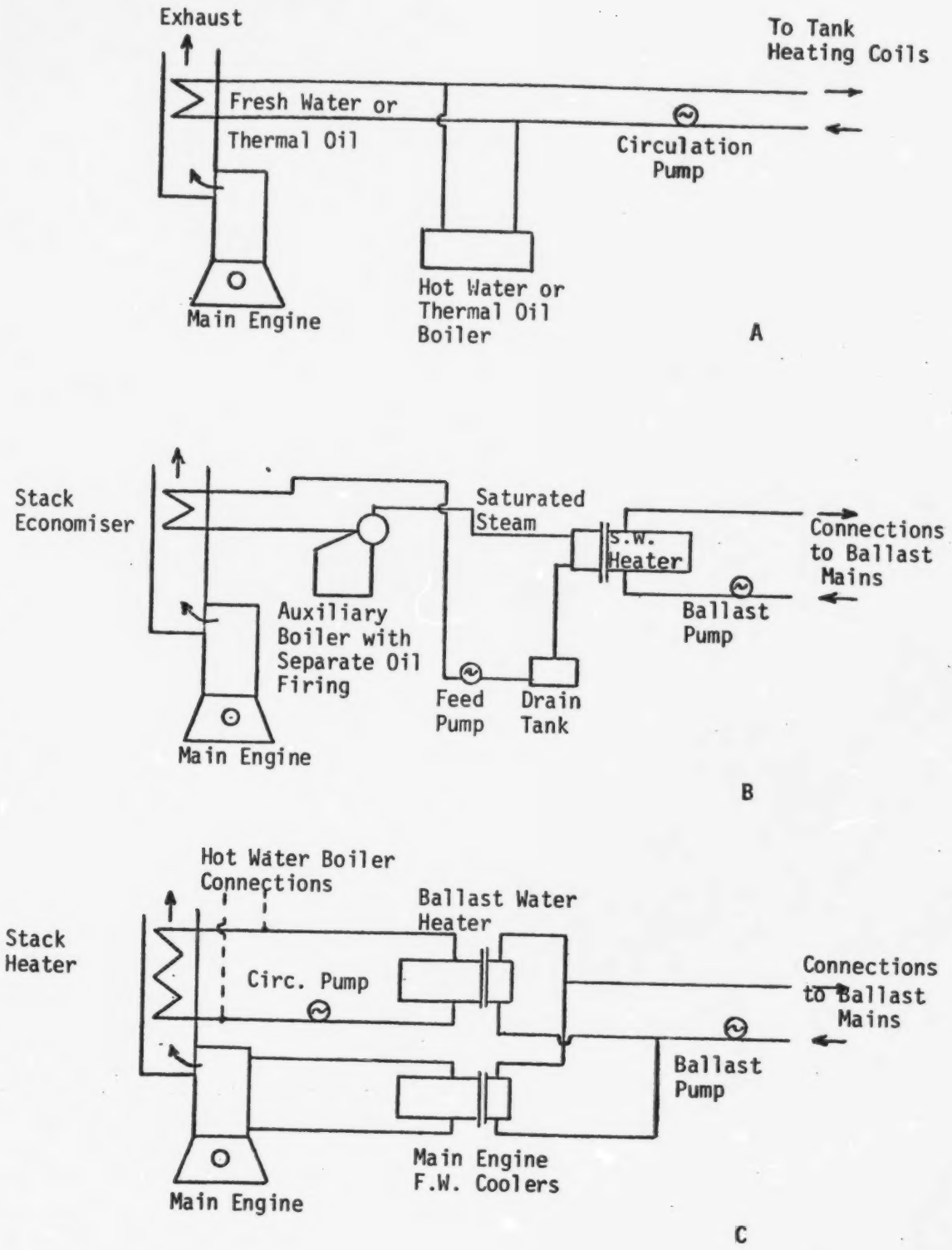


Figure 4 Alternative Ballast Water Heating Systems

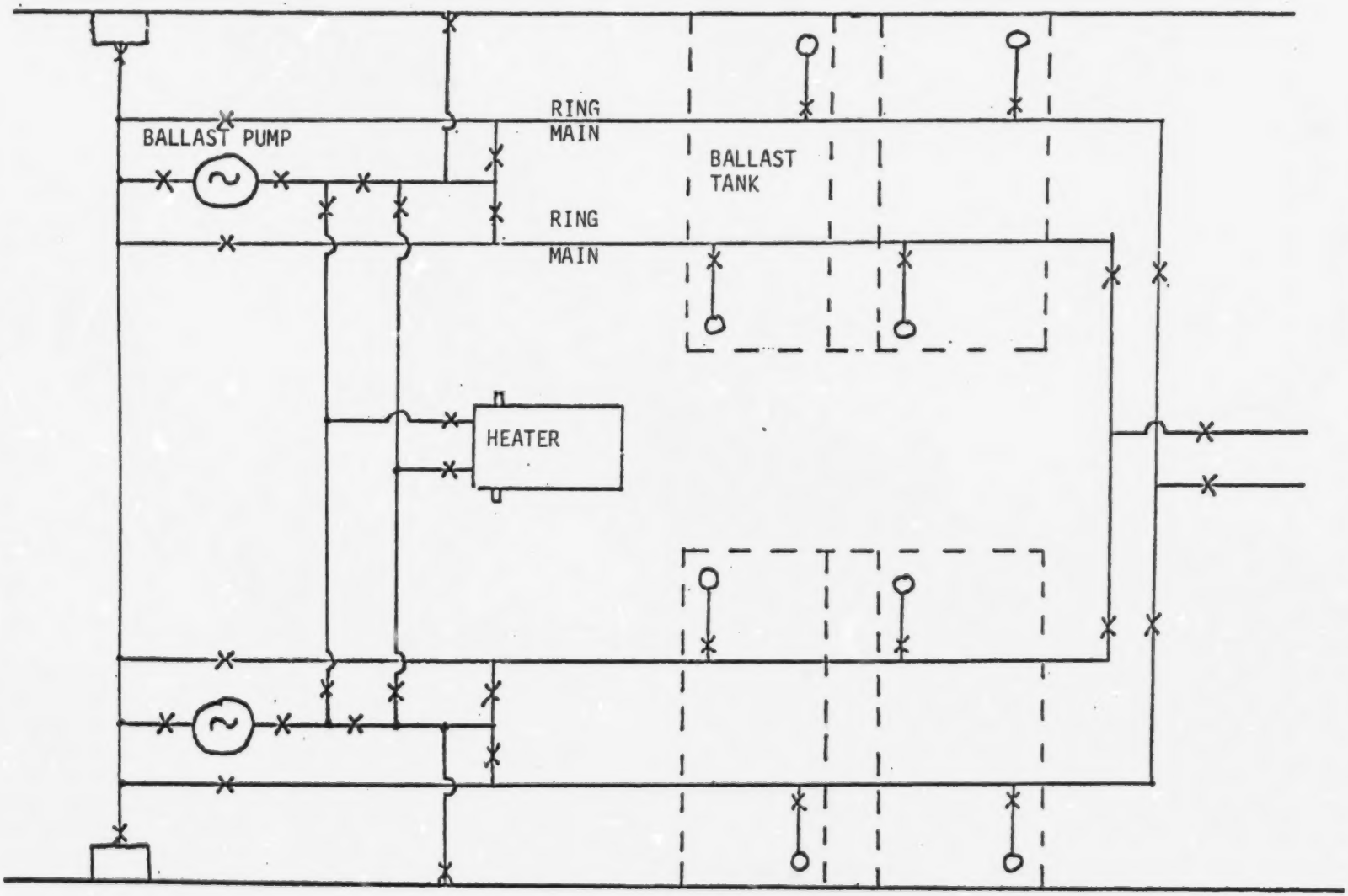


Figure 5 Ballast Piping Schematic

MIXED LAYER THICKNESS SB 007 19 MAY 1975
Throughly Mixed Layer at Snow Bird

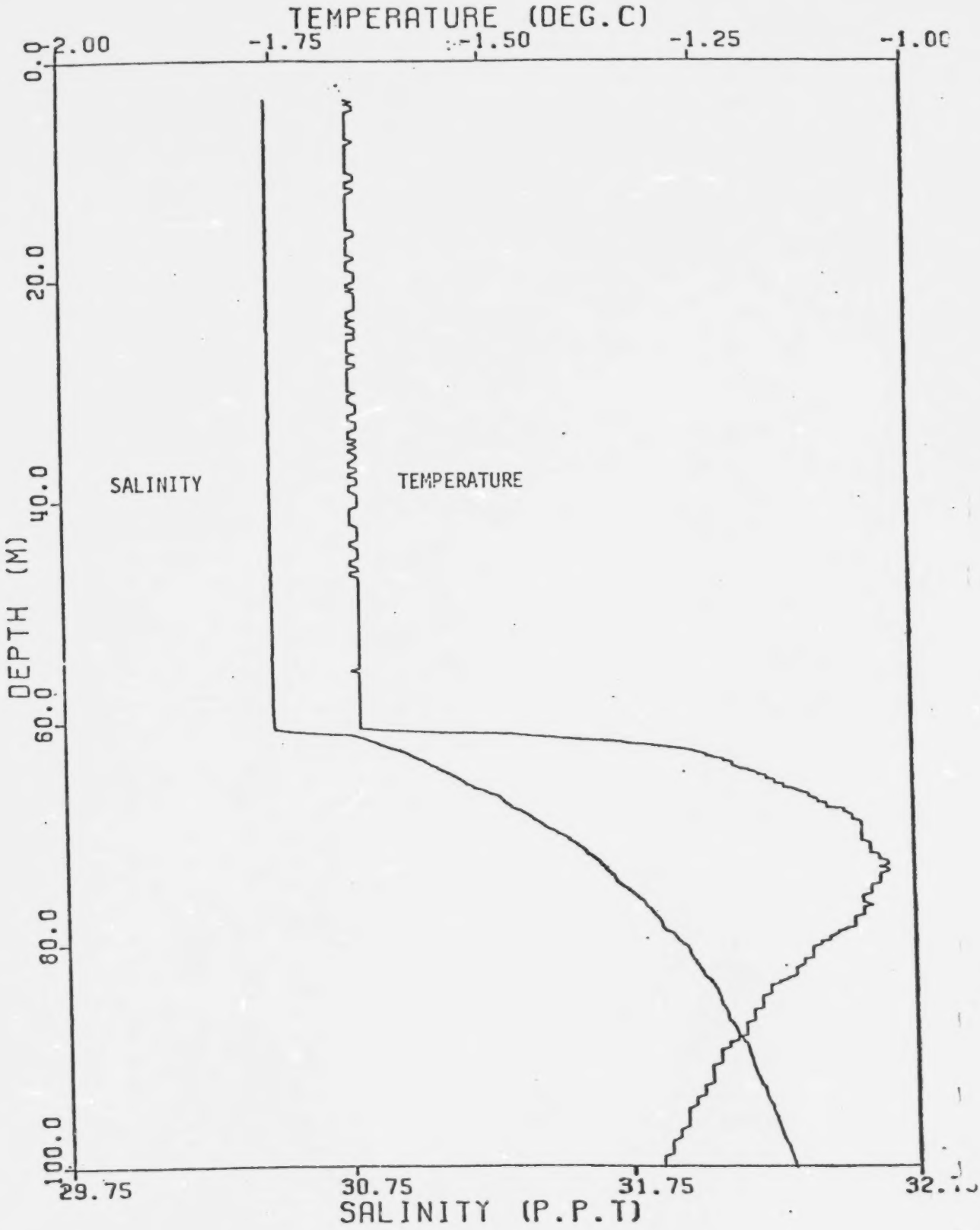


Figure 6 Temperature and Salinity Variation

MIXED LAYER THICKNESS CB 154 04 AUG 1975

Spacial Variability in Upper Layer at Caribou

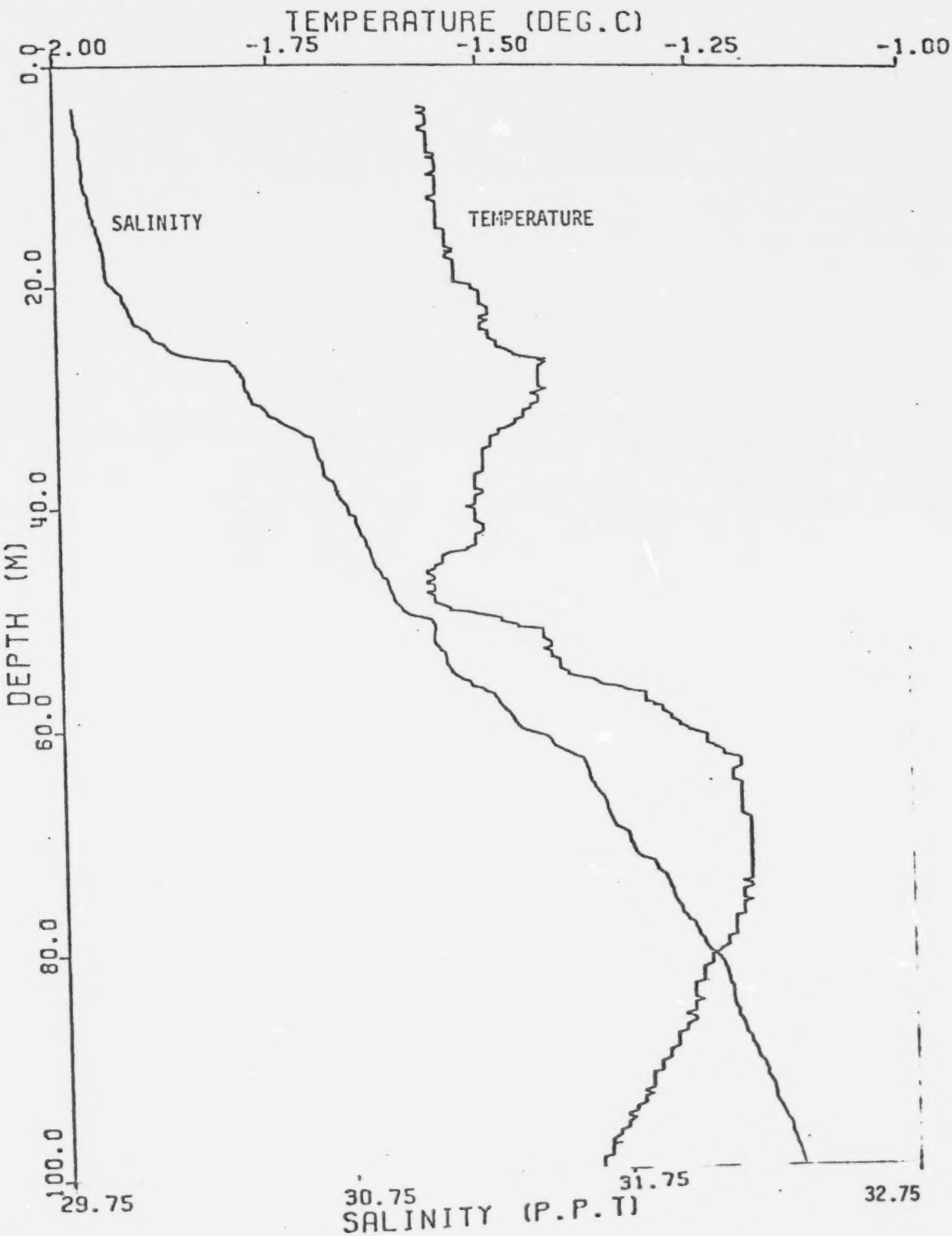


Figure 7 Temperature and Salinity Variation

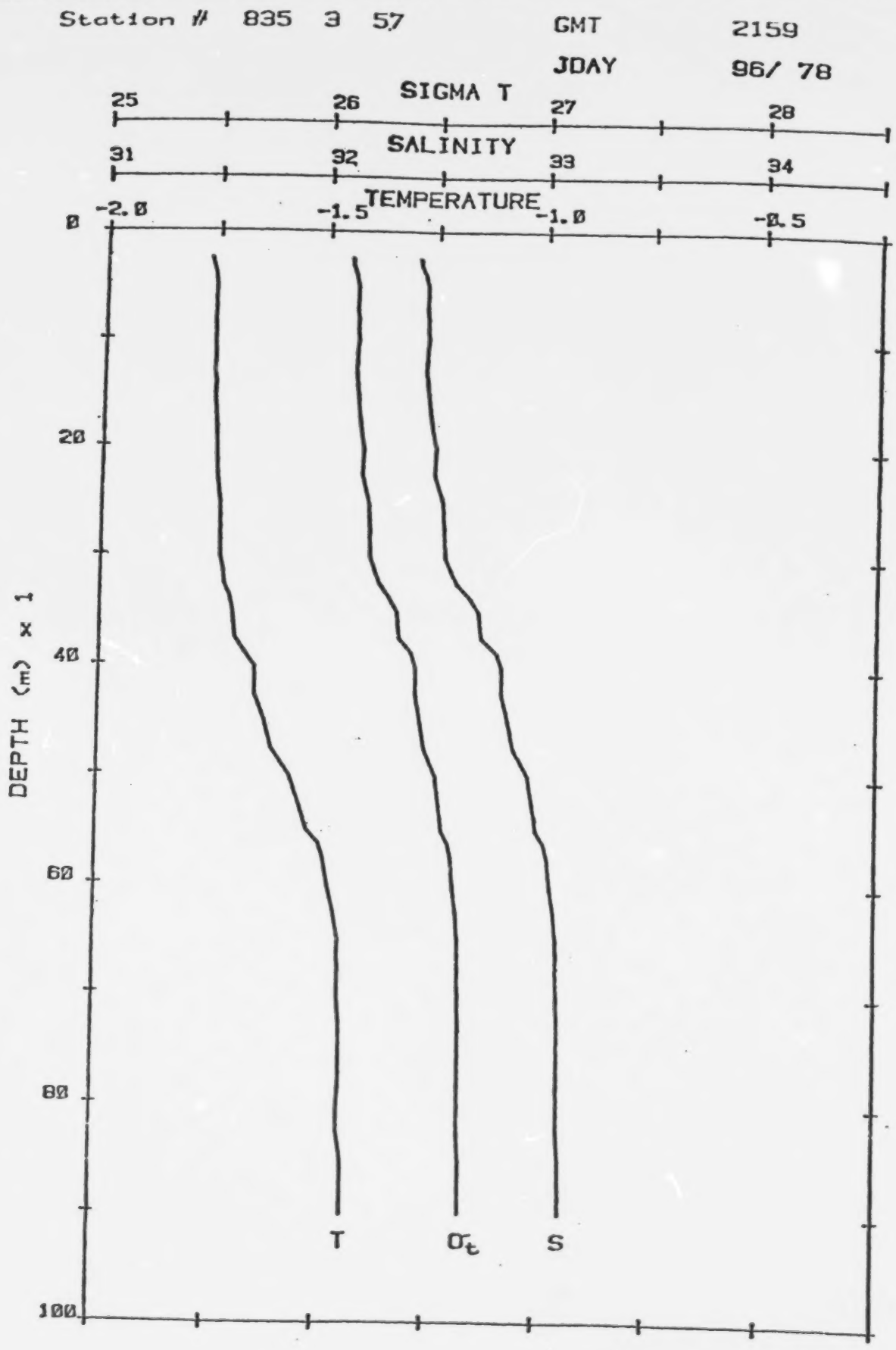
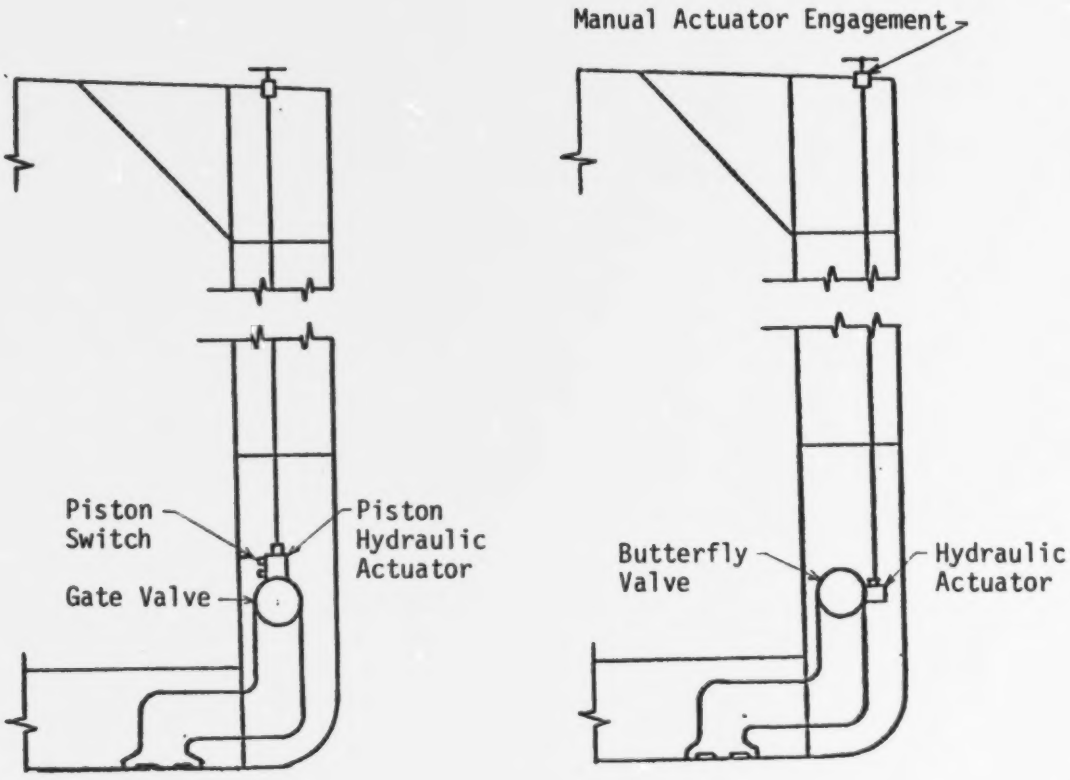


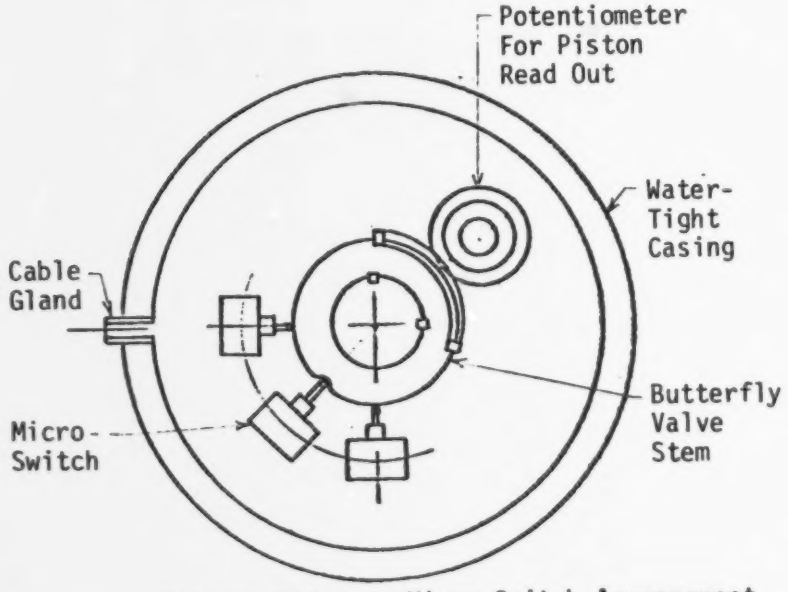
Figure 8 Temperature and Salinity Variation



Tank Arrangement Section

Potentiometer gives actual position of valve.

Micro-switch only indicates valve is open or closed. Intermediate position is indicated by third micro-switch.



Potentiometer or Micro-Switch Arrangement

Figure 9 Manual and Remote Control Valve Actuation

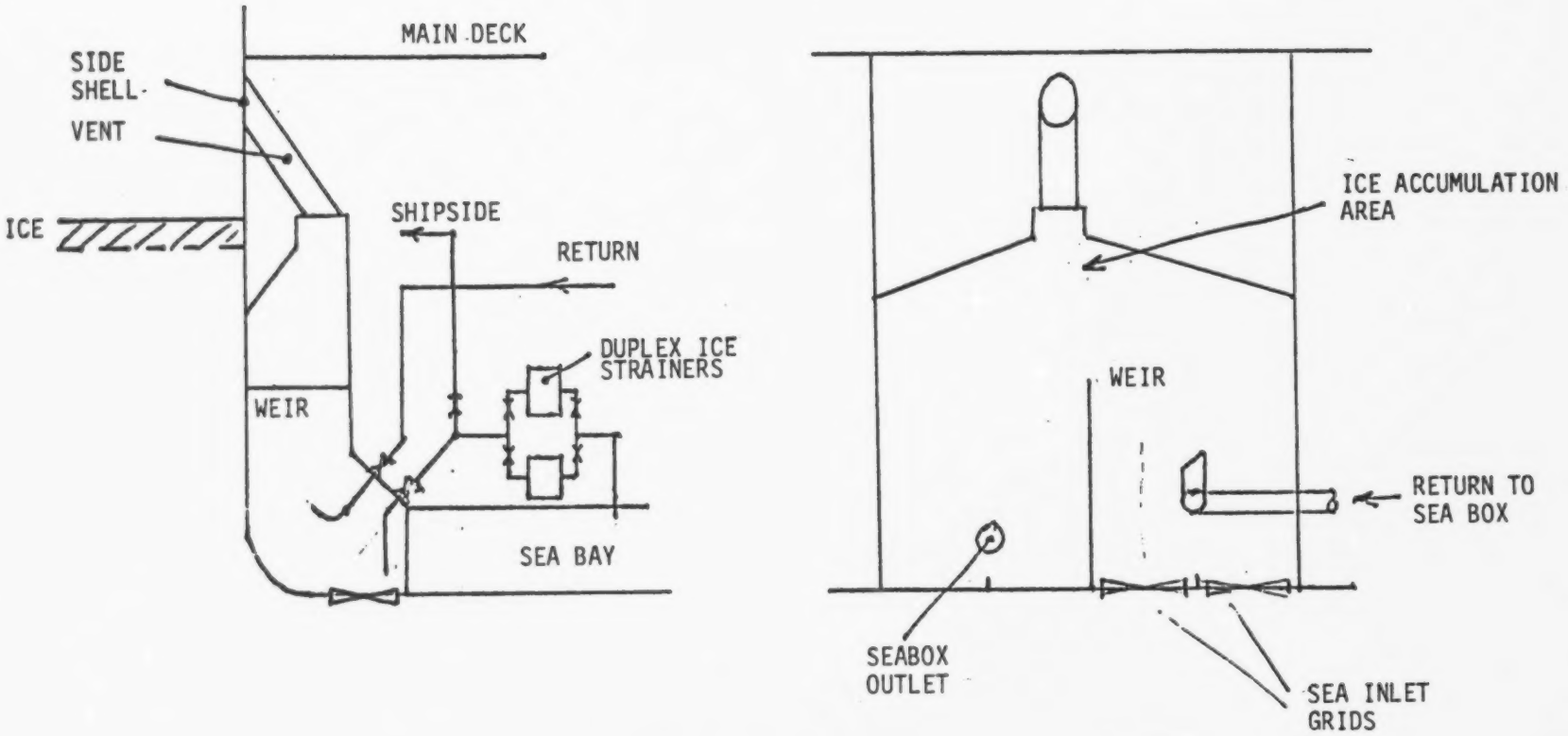


Figure 10 Sea Inlet Box Arrangement

REFERENCES

1. Some Mesoscale flow features in the Beaufort Sea during Aidjex 75-76 - Bharat Dixit PhD Thesis, McGill University, August 1978.

2. Heat Transmission - W. McAdams - McGraw Hill.

3. Marine application of thermal fluid heating - Inst. of Marine Engineers Trans. Vol. 90 Series A Part 3 of 7, 1978 - APW Slaughter - Wanson Company Ltd.

4. Arctic Oceanographic Data Report 1978 Volume 1 - S.J. Prinsenberg. Data Report Series No. 78-4. Fisheries and Environment Canada - Unpublished manuscript.

5. How to design tank heating coils - D. Stuhlbarg - Petroleum Refiner - April 1959.

APPENDIX A

QUESTIONNAIRE FOR DESIGNERS AND SHIPBUILDING DESIGN OFFICE ENGINEERS

Name _____

Company _____

Date _____

QUESTIONNAIRE FOR SHIP DESIGNERS AND
SHIPBUILDING DESIGN OFFICE ENGINEERS

1. Do you handle design work for ships operating in areas of freezing temperatures?

   Higher Arctic, Lower Arctic, Beaufort Sea ☐ YES ☐ NO

   Western & Eastern Seaboard, Lower St-Lawrence, Great Lakes ☐ YES ☐ NO

2. What type of ship designs normally lie within your scope?

   ☐ Ice breakers
   ☐ Drill rig supply vessels
   ☐ Survey and research vessels
   ☐ Ferries
   ☐ Bulk carriers
   ☐ Self-unloaders
   ☐ Breakbulks
   ☐ Container carriers
   ☐ Ro-Ro's
   ☐ Tugs
   ☐ Other(s)
   Please specify

   _____

   _____

   _____

   _____

QUESTIONNAIRE FOR SHIP DESIGNERS AND
SHIPBUILDING DESIGN OFFICE ENGINEERS (Cont'd)

3. Please elaborate on types or systems of ballasting you might specify for the different categories of ships listed above to operate in areas of freezing conditions?

Ship type	Ballast system
	Ringmain, Ballast manifold Duct Keel, other

4. What problems are you aware of in each of these ballast systems for freezing conditions?

5. What is the system for feedback of information to ship design offices regarding cold climate problems?

QUESTIONNAIRE FOR SHIP DESIGNERS AND
SHIPBUILDING DESIGN OFFICE ENGINEERS (Cont'd)

6. What advantages does one ballast system have over another for freezing conditions?

_____

_____

_____

_____

_____

7. What are the problems in the deficiency of the components for the different ballast system?

	Compatibility of system	Quality of design and/or of materials
Globe Valves	☐	☐
Gate Valves	☐	☐
Butterfly Valves	☐	☐
Pipe Couplings	☐	☐
Pipe Hangers	☐	☐
Pipe Fittings	☐	☐
Plastic Pipe	☐	☐
Electric, electronic controls	☐	☐

QUESTIONNAIRE FOR SHIP DESIGNERS AND
SHIPBUILDING DESIGN OFFICE ENGINEERS (Cont'd)

8. Do manufacturers of equipment specify temperature range limitations of their products? How do shipbuilders assess the same limitations for the systems? How are the temperatures decided?

9. What would you specify to contend with the rigorous conditions when ships experience extremely low ambient temperatures for the following fluid handling piping systems:

- Hydraulic winch systems

- Main and auxiliary machinery cooling systems

QUESTIONNAIRE FOR SHIP DESIGNERS AND
SHIPBUILDING DESIGN OFFICE ENGINEERS (Cont'd)

9. • Control and gauge piping valves and tubing

_____

_____

_____

_____

• Air bubbling antifriction systems

_____

_____

_____

_____

10. If quality and trouble free operation were the sole considerations in the design of any of these systems and components, what would you recommend be included in the specification?

_____

_____

_____

_____

_____

11. What provisions are made in owners specification for new ships to eliminate cold climate and ice related problems?

_____

_____

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_____

_____

QUESTIONNAIRE FOR SHIP DESIGNERS AND
SHIPBUILDING DESIGN OFFICE ENGINEERS (Cont'd)

12. Do you think that on going research should be encouraged for future design of ballast and other fluid handling systems for ships operating in areas of freezing temperatures? e.g. valves. Please elaborate.

_____

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Can we contact you for clarifications if necessary?

☐ NO ☐ YES Tel. (___) _____

APPENDIX B

QUESTIONNAIRE FOR PRIVATE SHIP OPERATORS

Name _____

Company _____

Date _____

QUESTIONNAIRE FOR PRIVATE SHIP OPERATORS

A. Do you operate in periods of freezing temperatures?

☐ YES

☐ NO (skip all other questions)

B. What types of ships and how many do you operate in periods of freezing temperatures?

Type of Ships	Number
☐ Bulk carrier(s)	_____
☐ Self-unloader(s)	_____
☐ Breakbulk package freighter(s)	_____
☐ Tanker(s)	_____
☐ Tug(s)	_____
☐ Drill Rig supply vessels	_____
☐ Other(s) Please specify	
_____	_____
_____	_____
_____	_____
_____	_____

C. In the following pages, list each type of ship where you experienced icing problems of ballast system and/or of other fluid handling systems, what components were affected, what was or were the cause(s) of the problem and how was it solved?

(Please fill one questionnaire for each type of ship)

QUESTIONNAIRE FOR PRIVATE SHIP OPERATORS (Cont'd)

1. Ship Type _____ Tonnage _____ Age _____ Years

   Length _____ Breadth _____ Draughts _____ Depth ___

   Propulsion System _____

   Waste Heat Recovery Systems _____

   Steam or Heating Capacity _____

   Electrical Power Generation Capacity _____

2. Area of operation in periods of freezing temperatures.

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Higher Arctic	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lower Arctic	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Beaufort Sea	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Western Seaboard	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Eastern Seaboard	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Great Lakes	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lower St-Lawrence	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

3. Please identify relevant climatic conditions:

   Minimum temperatures experienced _____

   Humidity _____

   Sea/ice states _____

   Wind strengths _____

   Type of ice _____

QUESTIONNAIRE FOR PRIVATE SHIP OPERATORS (Cont'd)

BALLAST SYSTEM

4. Type of ballasting system

- ☐ Ring Main Ballast System
- ☐ Port and starboard ballast manifold in the machinery space / with individual piping to each tank / hydraulic valves in the engine room
- ☐ Duct Keel System
- ☐ Other
  Please specify

_____
_____
_____
_____

5. Ballast tank arrangement

- ☐ Side tanks
- ☐ Shoulder or upper wing tanks
- ☐ Double bottom tanks
- ☐ Combination
  Please specify

_____
_____
_____
_____

6. How did/does problem manifest itself?
(frequency, operating conditions, etc.)

_____
_____
_____
_____

QUESTIONNAIRE FOR PRIVATE SHIP OPERATORS (Cont'd)

7. What was or were the cause(s) of the problem?

- ☐ Wrong operating procedures
- ☐ Poor choice of construction materials
- ☐ Poor (or deficient) design - Please specify _____
- ☐ Quality of valves
- ☐ Deficiency of hydraulic controls, ☐ of electric controls
- ☐ Poor choice of pipe materials
- ☐ Pipe hanger systems
- ☐ Poor pipe connectors
- ☐ Poor location of certain critical components - Please specify _____
- ☐ Other(s) Please specify

_____
_____
_____
_____

8. What components were affected by freezing in ballast system?

- ☐ Butterfly valve ☐ Globe valves ☐ Gate valves
- ☐ Valve seat ☐ Remote valve Spindles ☐ Electric & electronic controls
- ☐ Rubber seal
- ☐ Coupling between hydraulic valve and motor
- ☐ Suction bellmouth toe
- ☐ Piping
- ☐ Ballast tanks
- ☐ Other(s) Please specify

_____
_____
_____
_____

QUESTIONNAIRE FOR PRIVATE SHIP OPERATORS (Cont'd)

9. How was freezing problem corrected?

_____

_____

_____

_____

10. Has freezing problem been corrected permanently? If yes how?

☐ NO ☐ YES

- Piping

☐ Electrical heating

☐ Mechanical heating

☐ Submerged within contained ballast water

☐ Other(s)
Please specify

_____

_____

_____

_____

- Ballast Water

☐ Ballast Water recirculating in engine cooling system

☐ Air bubbling system under suction bellmouth toe

☐ Agitating water system

☐ Other(s)
Please specify

_____

_____

_____

_____

QUESTIONNAIRE FOR PRIVATE SHIP OPERATORS (Cont'd)

10. • Others (valves, ballast tank air vent, etc.)
Please specify

_____

_____

_____

_____

_____

_____

_____

_____

11. Has ship ever been delayed? If yes how long?

☐ No delay or _____ hours or _____ days

12. Was ship's stability hampered?

☐ NO ☐ YES { ☐ MARGINALLY ☐ CRITICALLY

13. Was ship's cargo deadweight or trading capability hampered?

☐ NO ☐ YES

14. In systems with known/identifiable problems to what extent is redundancy (back-up system) been built into the system?

_____

_____

_____

_____

_____

QUESTIONNAIRE FOR PRIVATE SHIP OPERATORS (Cont'd)

15. What provisions are made in owners specification for new ships to eliminate cold climate and ice related problems?

_____

_____

_____

_____

_____

16. What would be your recommendations to ship designers and builders of future ships to avoid freezing of ship ballasting system when operating in areas of freezing temperatures?

_____

_____

_____

_____

_____

OTHER FLUID HANDLING SYSTEMS

17. What other fluid handling systems were affected by freezing temperatures?

- ☐ Hydraulic winch system
- ☐ Piping. Specify system _____
- ☐ Engine cooling system sea valves and seabay
- ☐ Control gauge valves and tubing
- ☐ Other(s)
  Please specify

_____

_____

_____

_____

QUESTIONNAIRE FOR PRIVATE SHIP OPERATORS (Cont'd)

18. How did/does problem manifest itself?

_____

_____

_____

_____

19. What was or were the cause(s) of the problem?

- ☐ Wrong operating procedures
- ☐ Poor (or deficient) design
- ☐ Poor choice of construction materials
- ☐ Poor location of certain critical components - Please specify _____
- ☐ Other(s) Please specify

_____

_____

_____

_____

20. How was freezing problem corrected?

_____

_____

_____

_____

QUESTIONNAIRE FOR PRIVATE SHIP OPERATORS (Cont'd)

21. Has freezing problem been corrected permanently? If yes how?

☐ NO ☐ YES

☐ Adequate heating of hydraulic system particularly its control valves

☐ Relocation of component(s)
Please specify _____

☐ Other(s)
Please specify

_____

_____

_____

_____

22. What would be your recommendations to ship designers and builders of future ships to avoid freezing of fluid handling systems of ships operating in areas of freezing temperatures?

_____

_____

_____

_____

_____

23. In systems with known/identifiable problems to what extent is redundancy (back-up system) been built into the system?

_____

_____

_____

_____

_____

QUESTIONNAIRE FOR PRIVATE SHIP OPERATORS (Cont'd)

24. What provisions are made in owners specification for new ships to eliminate cold climate and ice related problems?

_____

_____

_____

_____

_____

25. Where do you think research should be encouraged? (for ballasting systems and for other fluid handling systems / in existing and in new ships)

_____

_____

_____

_____

_____

QUESTIONNAIRE FOR PRIVATE SHIP OPERATORS (Cont'd)

If you wish to elaborate on some answers please do so.

Can we contact you for clarifications if necessary?

☐ NO ☐ YES Tel. (___) _____

APPENDIX C

QUESTIONNAIRE FOR GOVERNMENT SHIP OPERATORS

Name _____

Organization _____

Date _____

QUESTIONNAIRE FOR GOVERNMENT SHIP OPERATORS

A. Do you operate in periods of freezing temperatures?

- ☐ YES
- ☐ NO (skip all other questions)

B. What types of ships and how many do you operate in periods of freezing temperatures?

- ☐ Ice breaker(s) _____
- ☐ Survey and research vessel(s) _____
- ☐ Ferries _____
- ☐ Other(s)
  Please specify

_____ _____

_____ _____

_____ _____

_____ _____

C. In the following pages, list each type of ship where you experienced icing problems of ballast system and/or of fluid handling systems, what components were affected, what was or were the cause(s) of the problem and how was it solved?

(Please fill one questionnaire for each type of ship)

QUESTIONNAIRE FOR GOVERNMENT SHIP OPERATORS (Cont'd)

1. Ship Type _____ Tonnage _____ Age _____ Years

   Length _____ Breadth _____ Draughts _____ Depth ____

   Propulsion System _____

   Waste Heat Recovery Systems _____

   Steam or Heating Capacity _____

   Electrical Power Generation Capacity _____

2. Area of operation in periods of freezing temperatures.

	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Higher Arctic	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lower Arctic	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Beaufort Sea	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Western Seaboard	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Eastern Seaboard	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Great Lakes	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lower St-Lawrence	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐

3. Please identify relevant climatic conditions:

   Minimum temperatures experienced _____

   Humidity _____

   Sea/ice states _____

   Wind strengths _____

   Type of ice _____

QUESTIONNAIRE FOR GOVERNMENT SHIP OPERATORS (Cont'd)

BALLAST SYSTEM

4. Type of ballasting system

- ☐ Ring Main Ballast System
- ☐ Port and starboard ballast manifold in the machinery space / with individual piping to each tank / hydraulic valves in the engine room
- ☐ Duct Keel System
- ☐ Flume stabilization / Induced heeling and trimming
- ☐ Other
  Please specify

_____
_____
_____
_____

5. Ballast tank arrangement

- ☐ Side tanks
- ☐ Shoulder or upper wing tanks
- ☐ Double bottom tanks
- ☐ Combination
  Please specify

_____
_____
_____
_____

6. How did/does problem manifest itself?
(frequency, operating conditions, etc.)

_____
_____
_____
_____

QUESTIONNAIRE FOR GOVERNMENT SHIP OPERATORS (Cont'd)

7. What was or were the cause(s) of the problem?

- ☐ Wrong operating procedures
- ☐ Poor choice of construction materials
- ☐ Poor (or deficient) design - Please specify _____
- ☐ Quality of valves
- ☐ Deficiency of hydraulic controls, ☐ of electric controls
- ☐ Poor choice of pipe materials
- ☐ Pipe hanger systems
- ☐ Poor pipe connectors
- ☐ Poor location of certain critical components - Please specify _____
- ☐ Other(s) Please specify

_____
_____
_____
_____

8. What components were affected by freezing in ballast system?

- ☐ Butterfly valve ☐ Globe valves ☐ Gate valves
- ☐ Valve seat ☐ Remote valve Spindles ☐ Electric & electronic controls
- ☐ Rubber seal
- ☐ Coupling between hydraulic valve and motor
- ☐ Suction bellmouth toe
- ☐ Piping
- ☐ Ballast tanks
- ☐ Other(s) Please specify

_____
_____
_____
_____

QUESTIONNAIRE FOR GOVERNMENT SHIP OPERATORS (Cont'd)

9. How was freezing problem corrected?

_____

_____

_____

_____

10. Has freezing problem been corrected permanently? If yes how?

☐ NO ☐ YES

- Piping

☐ Electrical heating

☐ Mechanical heating

☐ Submerged within contained ballast water

☐ Other(s)
Please specify

_____

_____

_____

_____

- Ballast Water

☐ Ballast Water recirculating in engine cooling system

☐ Air bubbling system under suction bellmouth toe

☐ Agitating water system

☐ Other(s)
Please specify

_____

_____

_____

_____

QUESTIONNAIRE FOR GOVERNMENT SHIP OPERATORS (Cont'd)

10. • Others (valves, ballast tank air vent, etc.)
Please specify

_____
_____
_____
_____
_____
_____
_____
_____

11. Has ship ever been delayed? If yes how long?
☐ No delay or ____ hours or _____ days

12. Was ship's stability hampered?
☐ NO ☐ YES { ☐ MARGINALLY ☐ CRITICALLY

13. Was ship's cargo deadweight or trading/operating capability hampered?
☐ NO ☐ YES

14. In systems with known/identifiable problems to what extent is redundancy (back-up system) been built into the system?

_____
_____
_____
_____
_____

QUESTIONNAIRE FOR GOVERNMENT SHIP OPERATORS (Cont'd)

15. What provisions are made in owners specification for new ships to eliminate cold climate and ice related problems?

_____

_____

_____

_____

_____

16. What would be your recommendations to ship designers and builders of future ships to avoid freezing of ship ballasting system when operating in areas of freezing temperatures?

_____

_____

_____

_____

_____

OTHER FLUID HANDLING SYSTEMS

17. What other fluid handling systems were affected by freezing temperatures?

- ☐ Hydraulic winch system
- ☐ Piping. Specify system _____
- ☐ Engine cooling system sea valves and seabay
- ☐ Control gauge valves and tubing
- ☐ Air bubbler friction reducing system
- ☐ Tank level gauges air bubbler system
- ☐ Other(s)
  Please specify

_____

_____

_____

_____

QUESTIONNAIRE FOR GOVERNMENT SHIP OPERATORS (Cont'd)

18. How did/does problem manifest itself?

_____

_____

_____

_____

19. What was or were the cause(s) of the problem?

- ☐ Wrong operating procedures
- ☐ Poor (or deficient) design
- ☐ Poor choice of construction materials
- ☐ Poor location of certain critical components - Please specify _____
- ☐ Other(s) Please specify

_____

_____

_____

_____

20. How was freezing problem corrected?

_____

_____

_____

_____

QUESTIONNAIRE FOR GOVERNMENT SHIP OPERATORS (Cont'd)

21. Has freezing problem been corrected permanently? If yes how?

☐ NO ☐ YES

☐ Adequate heating of hydraulic system particularly its control valves

☐ Relocation of component(s)
Please specify _____

☐ Other(s)
Please specify

_____

_____

_____

_____

22. What would be your recommendations to ship designers and builders of future ships to avoid freezing of fluid handling systems of ships operating in areas of freezing temperatures?

_____

_____

_____

_____

_____

23. In systems with known/identifiable problems to what extent is redundancy (back-up system) been built into the system?

_____

_____

_____

_____

_____

QUESTIONNAIRE FOR GOVERNMENT SHIP OPERATORS (Cont'd)

24. What provisions are made in owners specification for new ships to eliminate cold climate and ice related problems?

_____

_____

_____

_____

_____

25. Where do you think research should be encouraged? (for ballasting systems and for other fluid handling systems / in existing and in new ships)

_____

_____

_____

_____

_____

QUESTIONNAIRE FOR GOVERNMENT SHIP OPERATORS (Cont'd)

If you wish to elaborate on some answers please do so.

Can we contact you for clarifications if necessary?

☐ NO ☐ YES Tel. (___) _____

POOR

QUALITY

ORIGINAL